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**Kodama et al.**

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(54) **OPTICAL AND ELECTRICAL CIRCUIT BOARD AND METHOD OF MANUFACTURING THE SAME**

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**G02B 6/26** (2006.01)  
**G02B 6/42** (2006.01)

(52) **U.S. Cl.** ..... **385/14; 385/33; 385/47**

(58) **Field of Classification Search** ..... **385/14, 385/33-35, 47-49**

See application file for complete search history.

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*Primary Examiner*—Uyen-Chau N Le

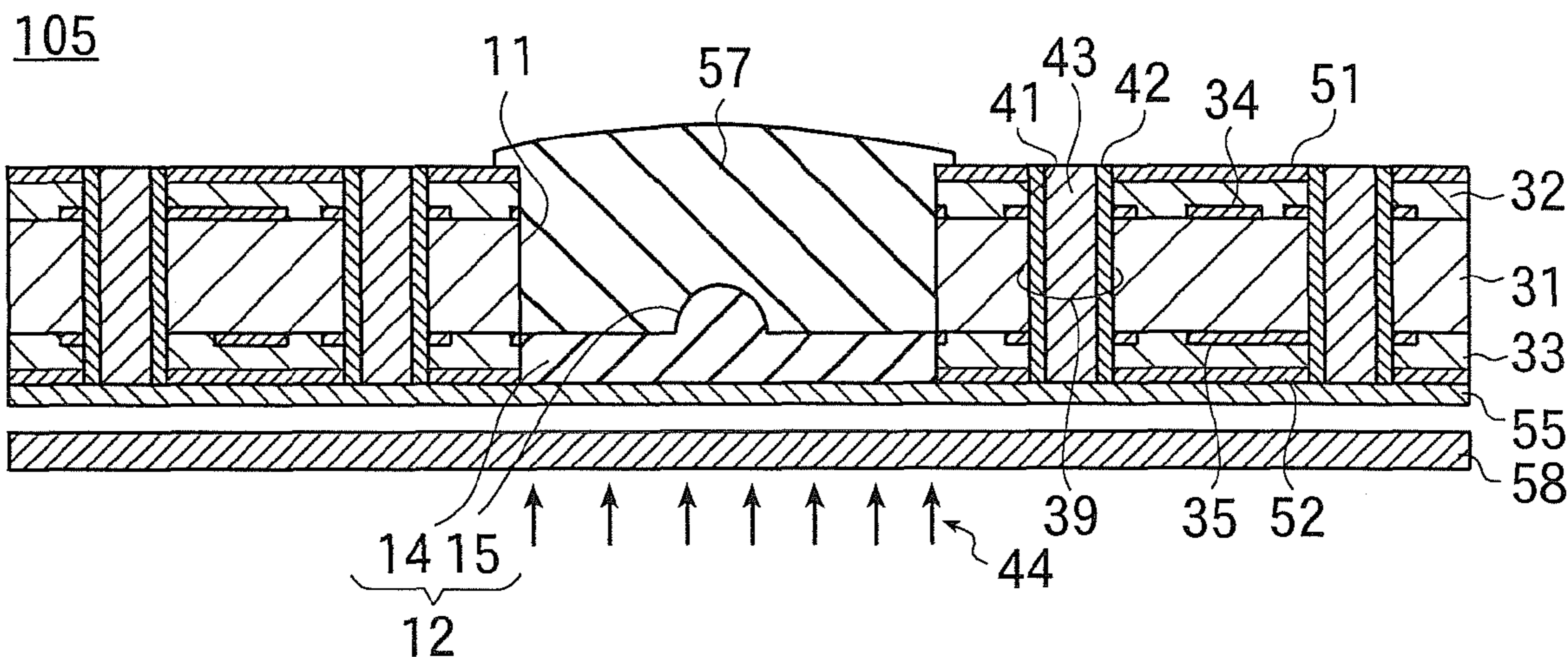
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(57) **ABSTRACT**

An optical and electrical circuit board includes a patterned electrical wiring and a micro convex lens. The micro convex lens is provided in at least one hole formed in the optical and electrical circuit board.

**9 Claims, 13 Drawing Sheets**



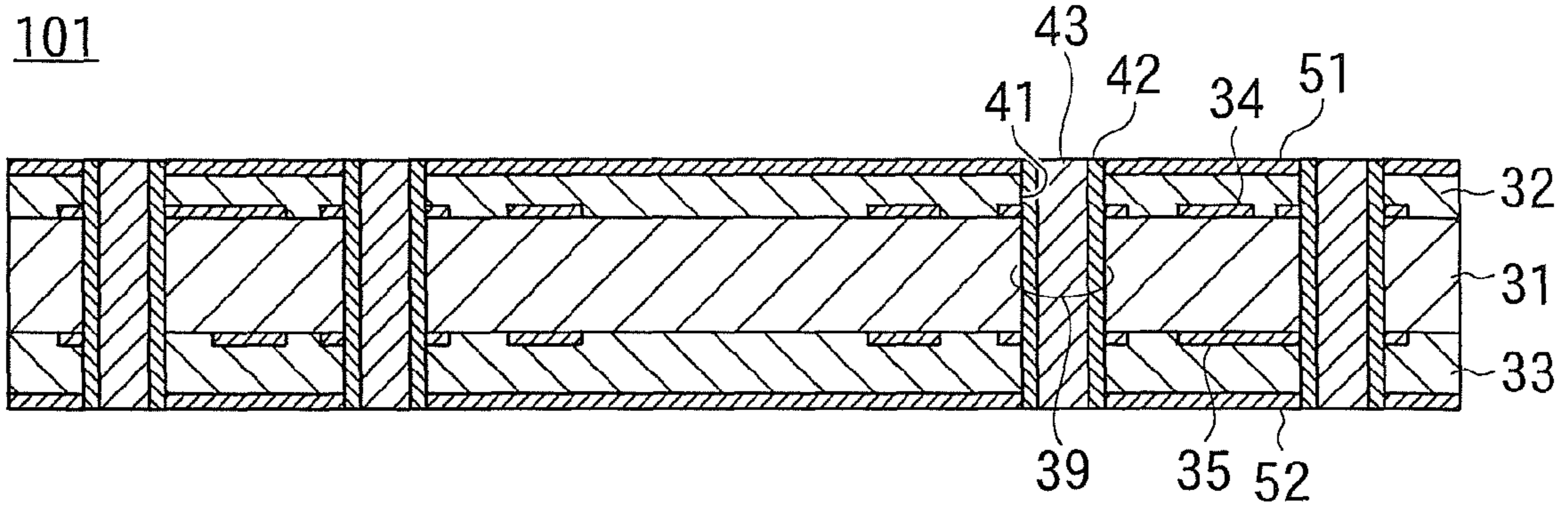


Fig. 1A

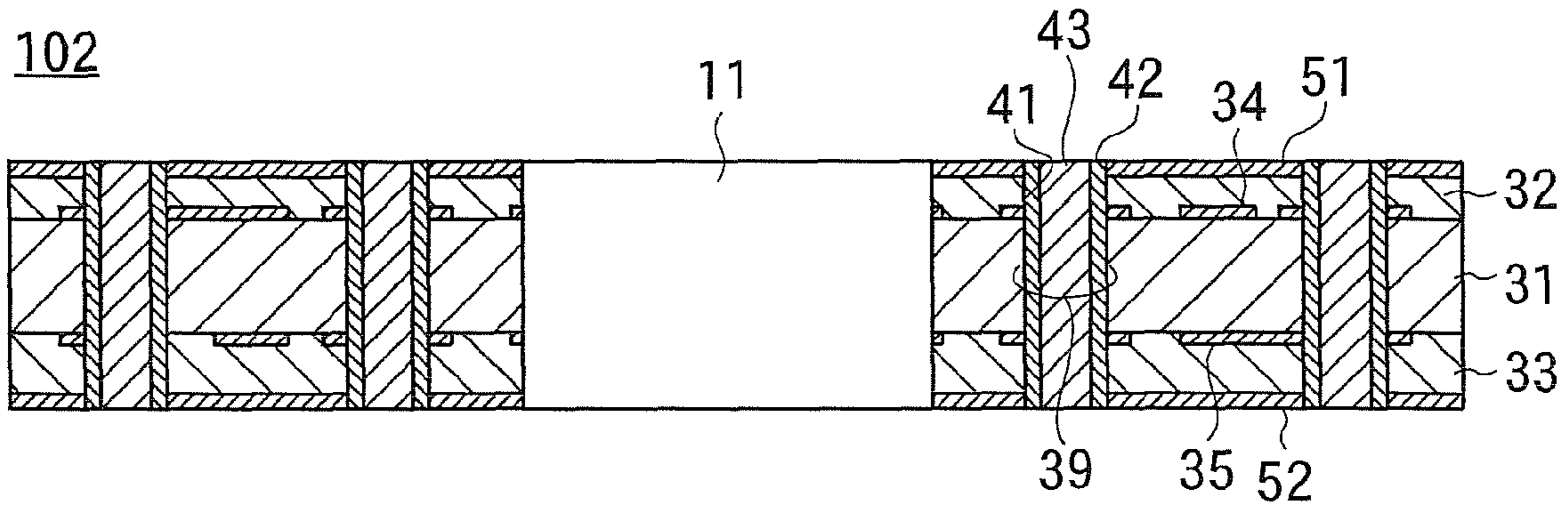


Fig. 1B

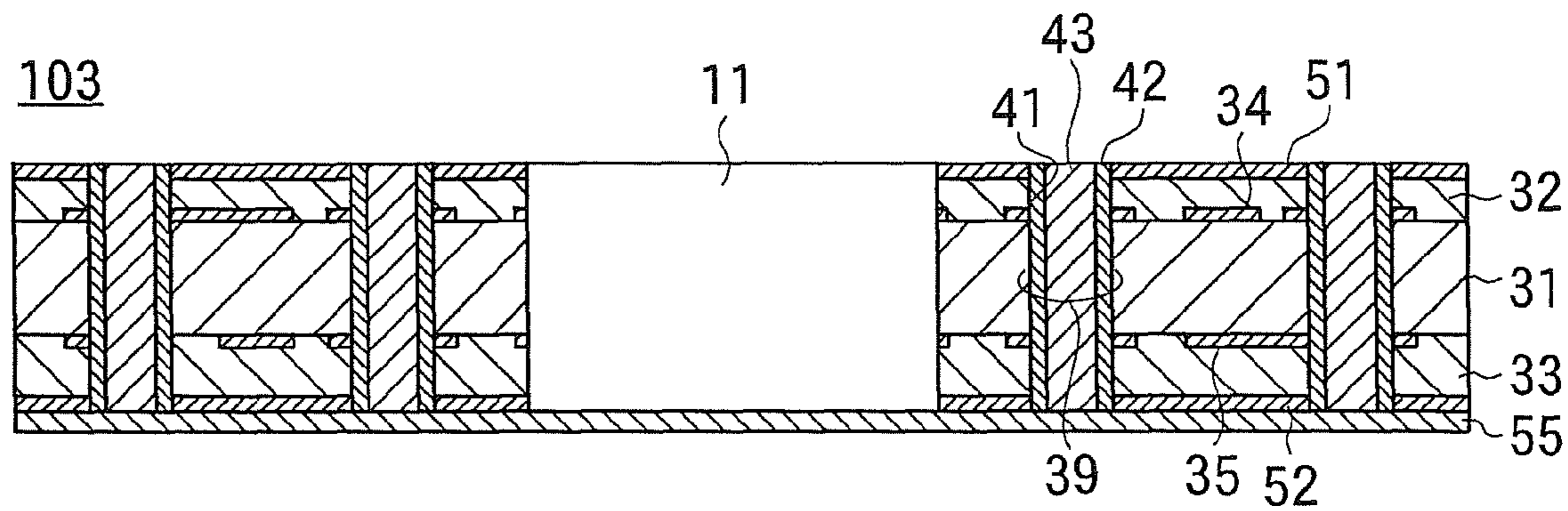


Fig. 1C

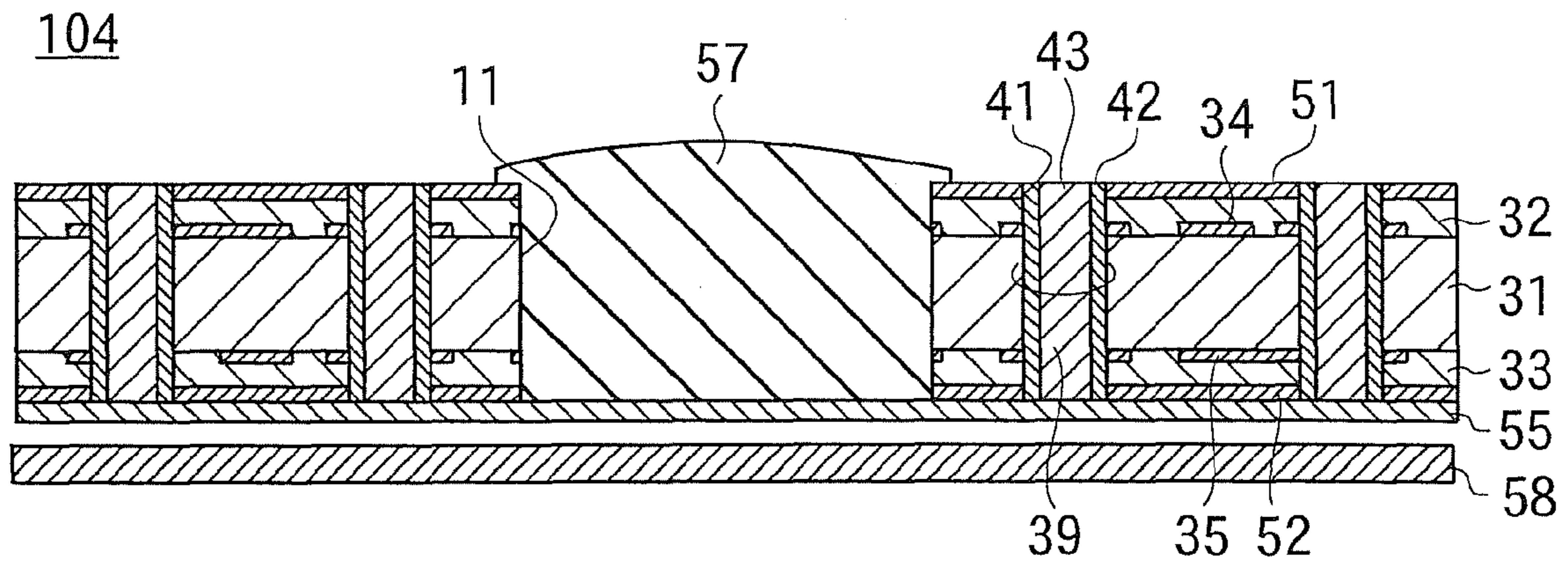


Fig. 2A

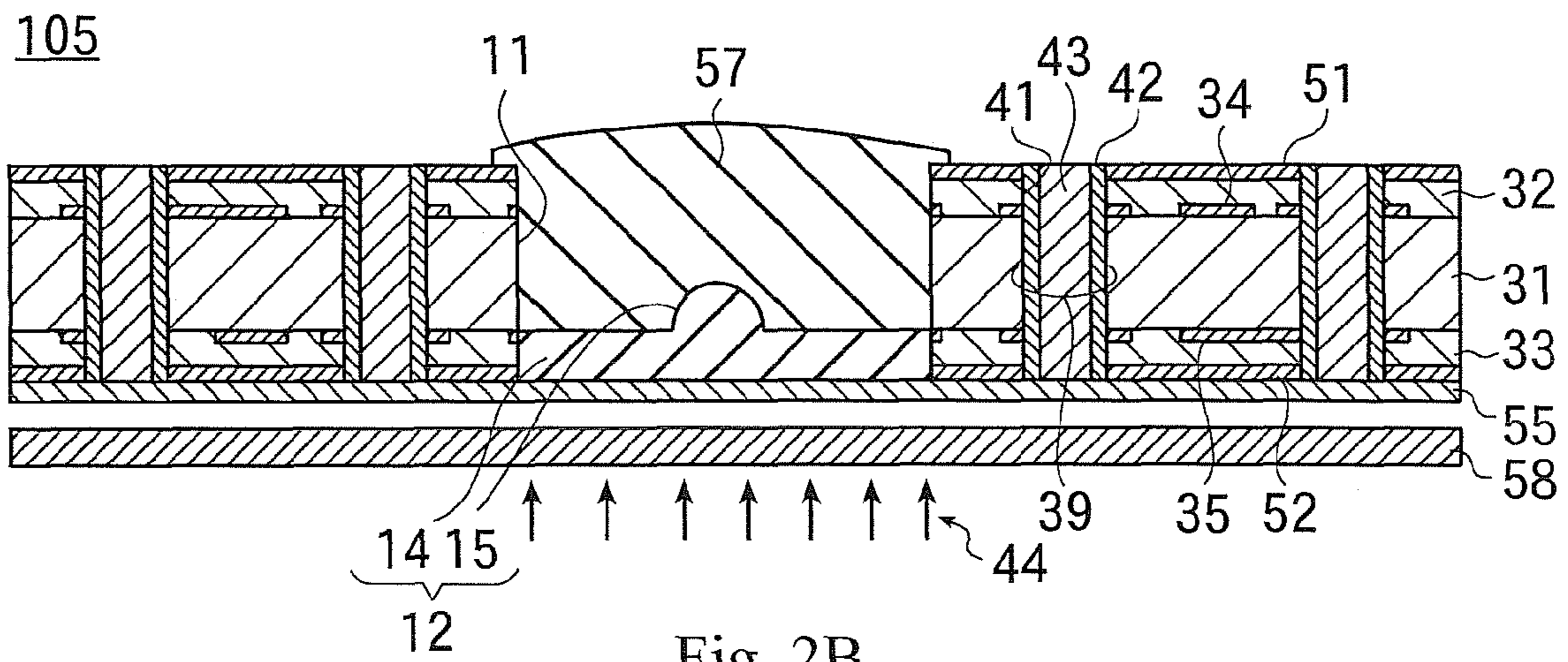


Fig. 2B

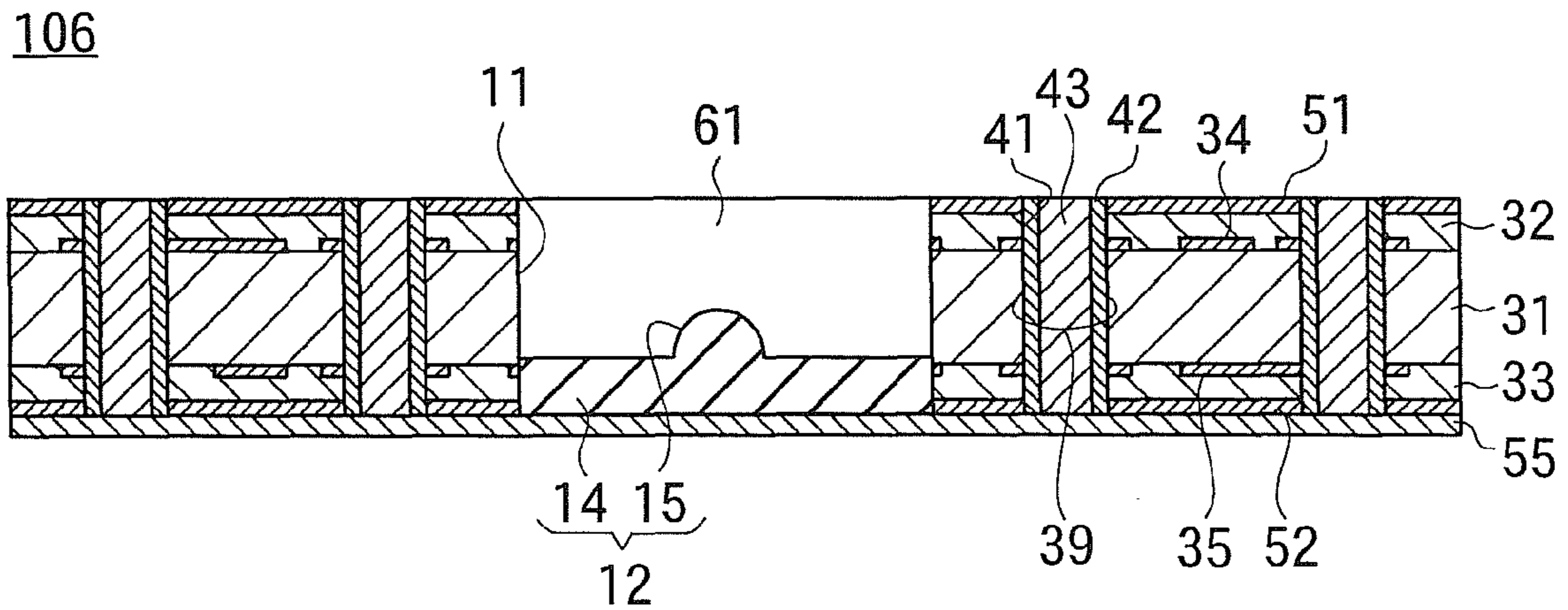


Fig. 2C

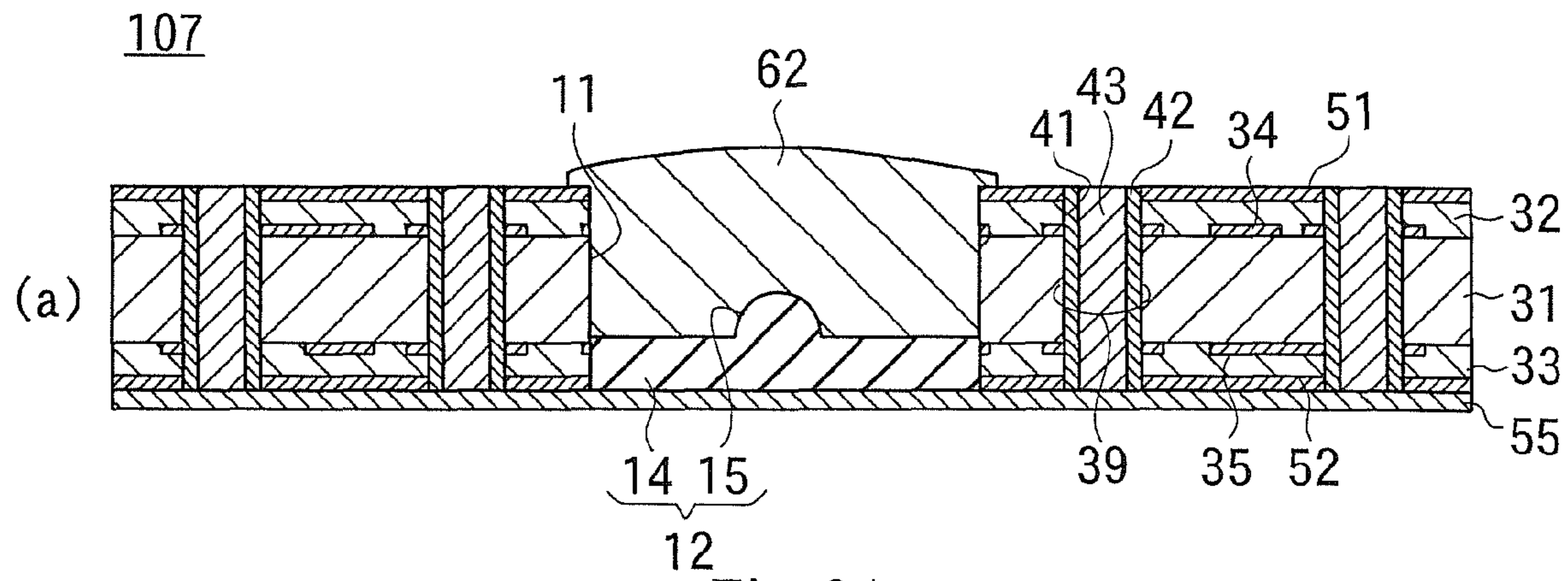


Fig. 3A

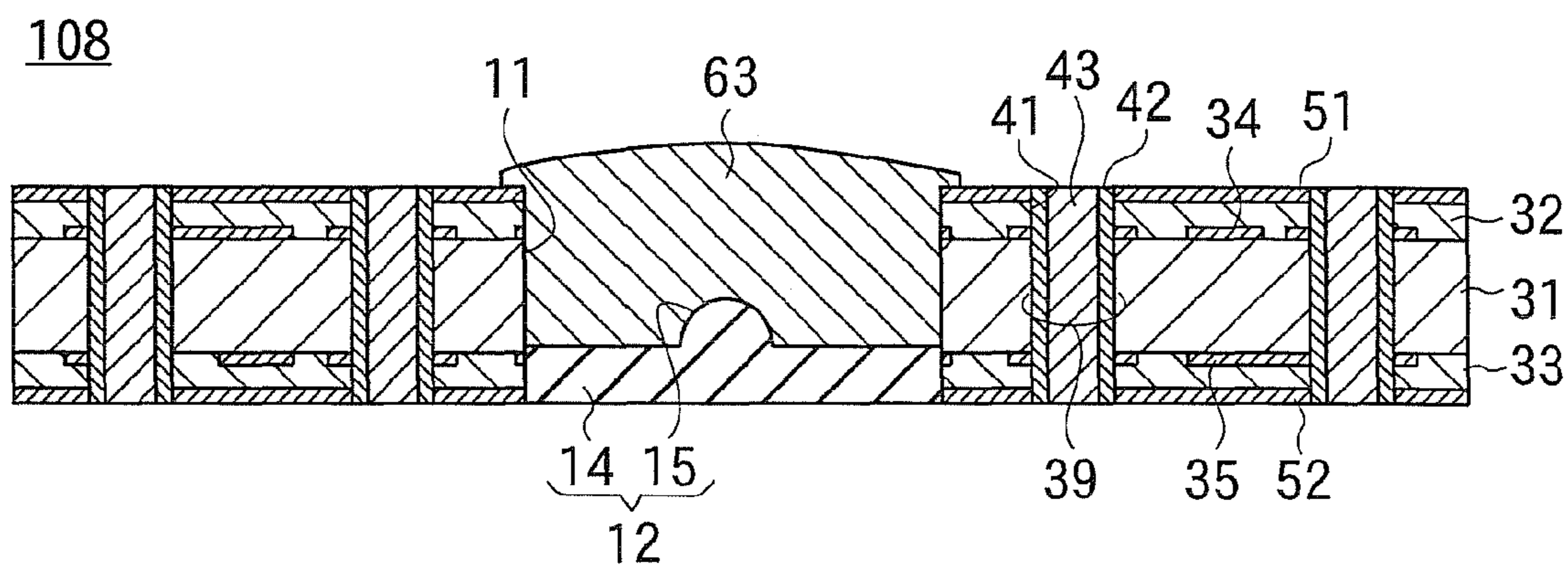


Fig. 3B

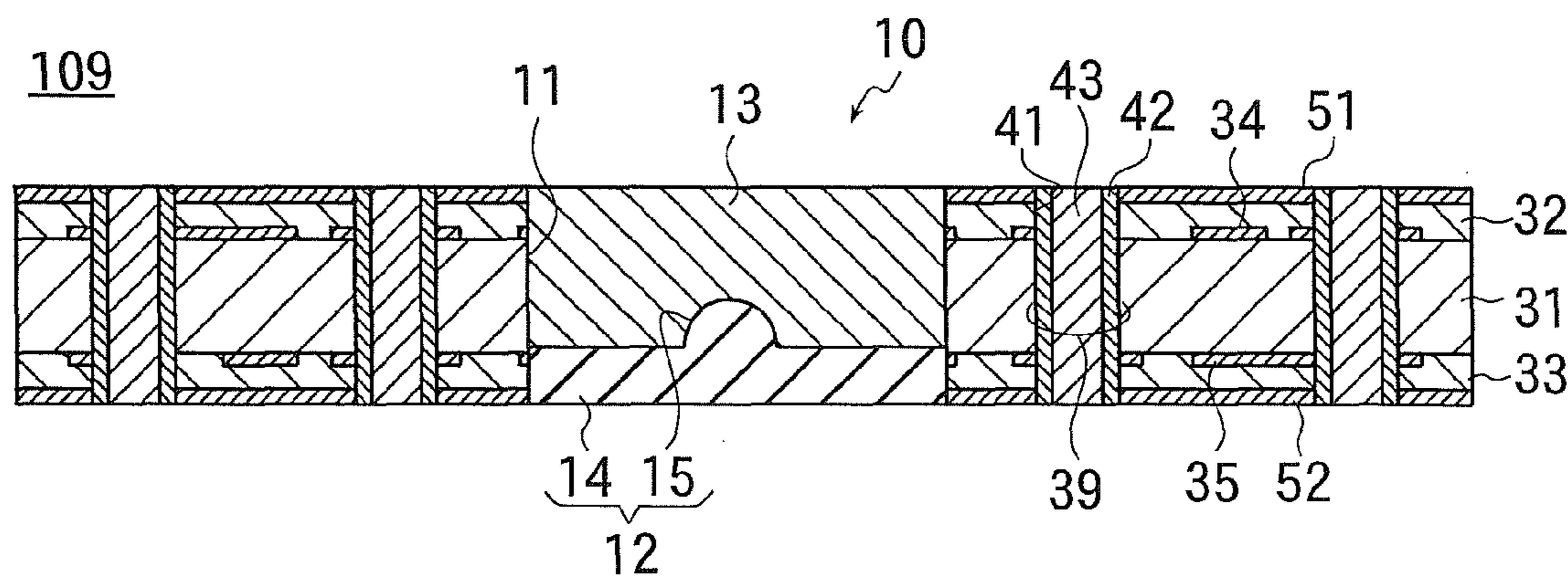


Fig. 3C

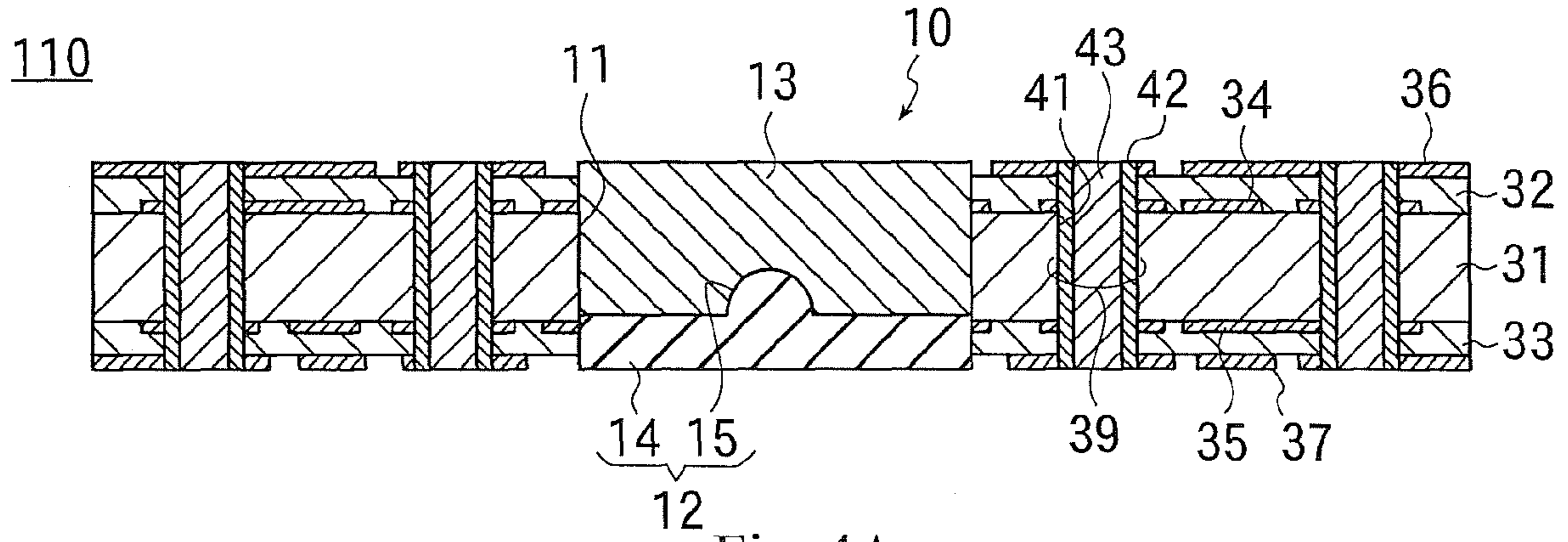


Fig. 4A

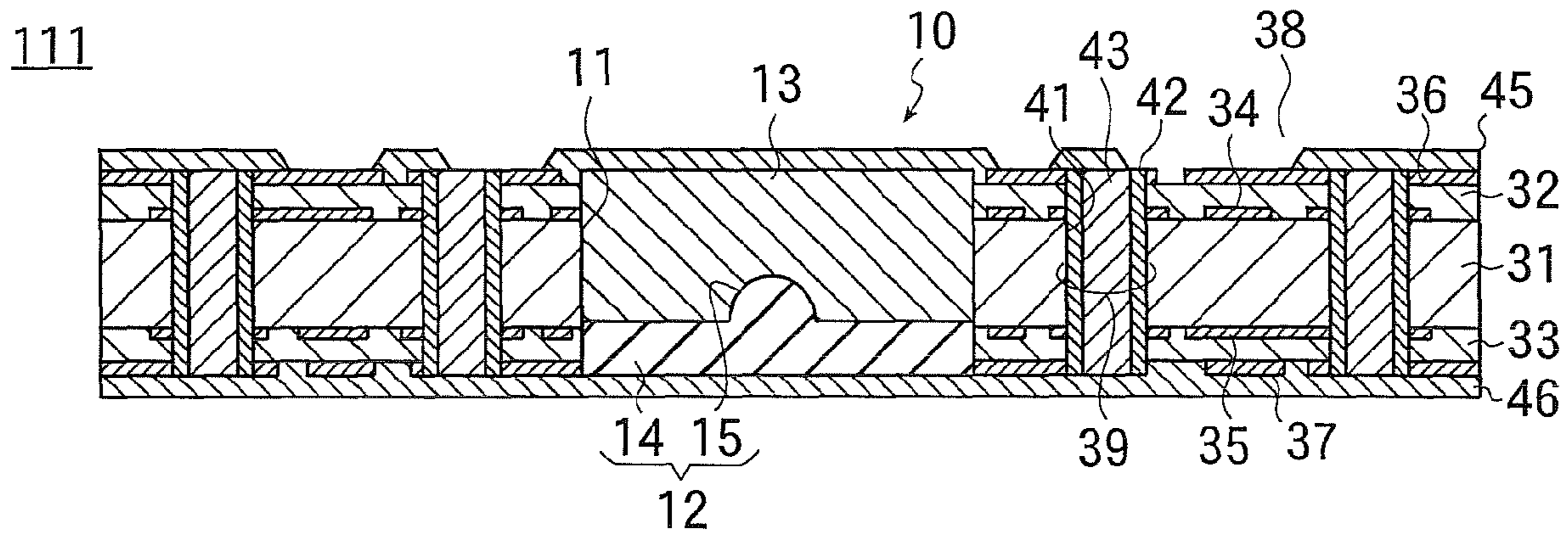


Fig. 4B

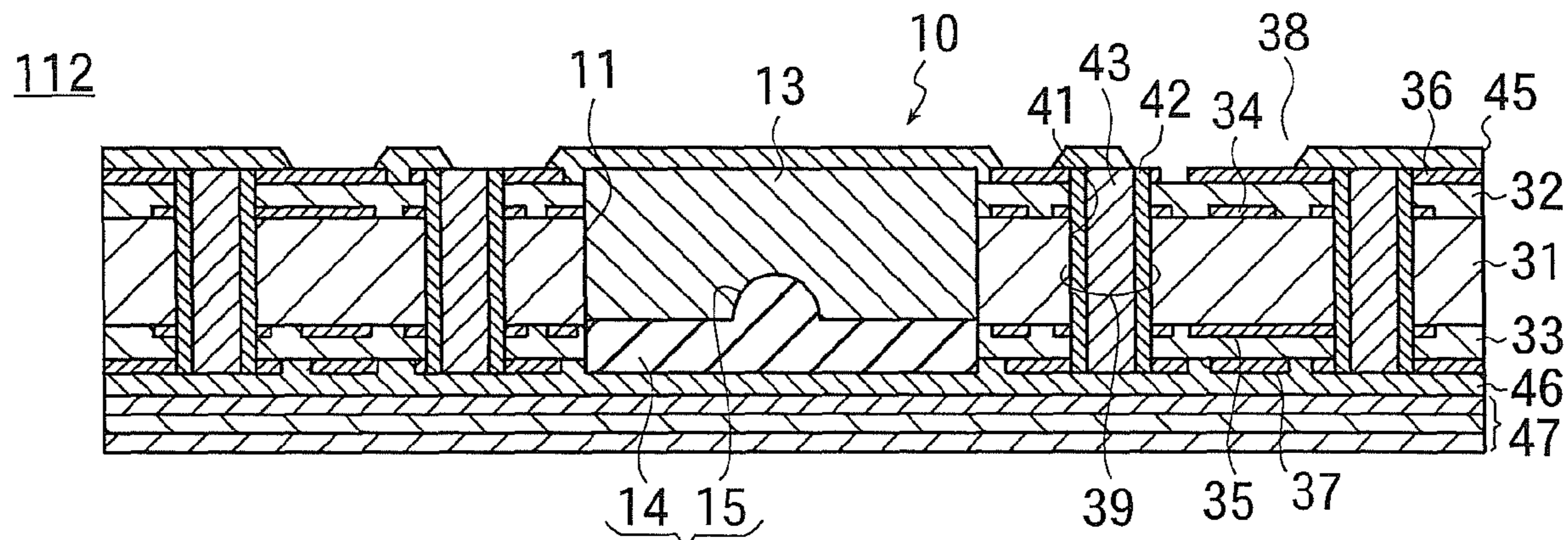


Fig. 4C

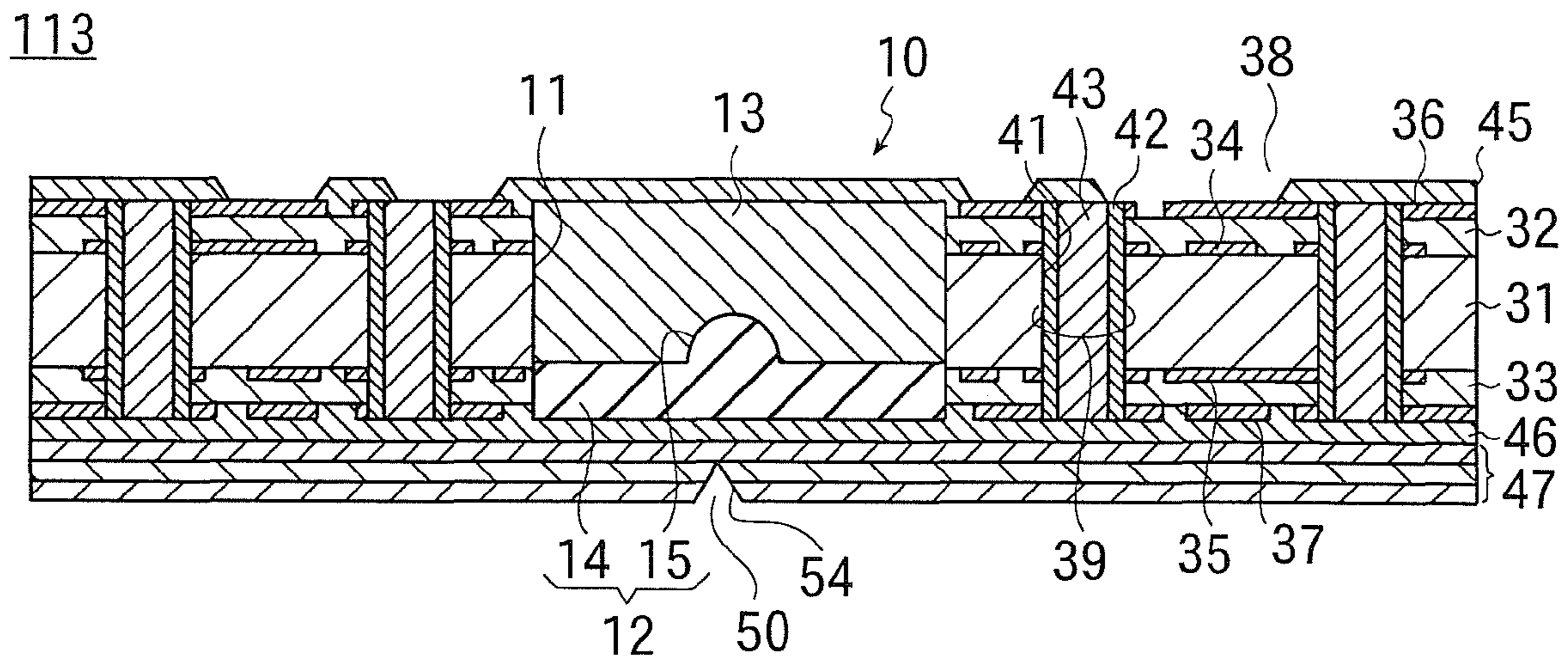


Fig. 5A

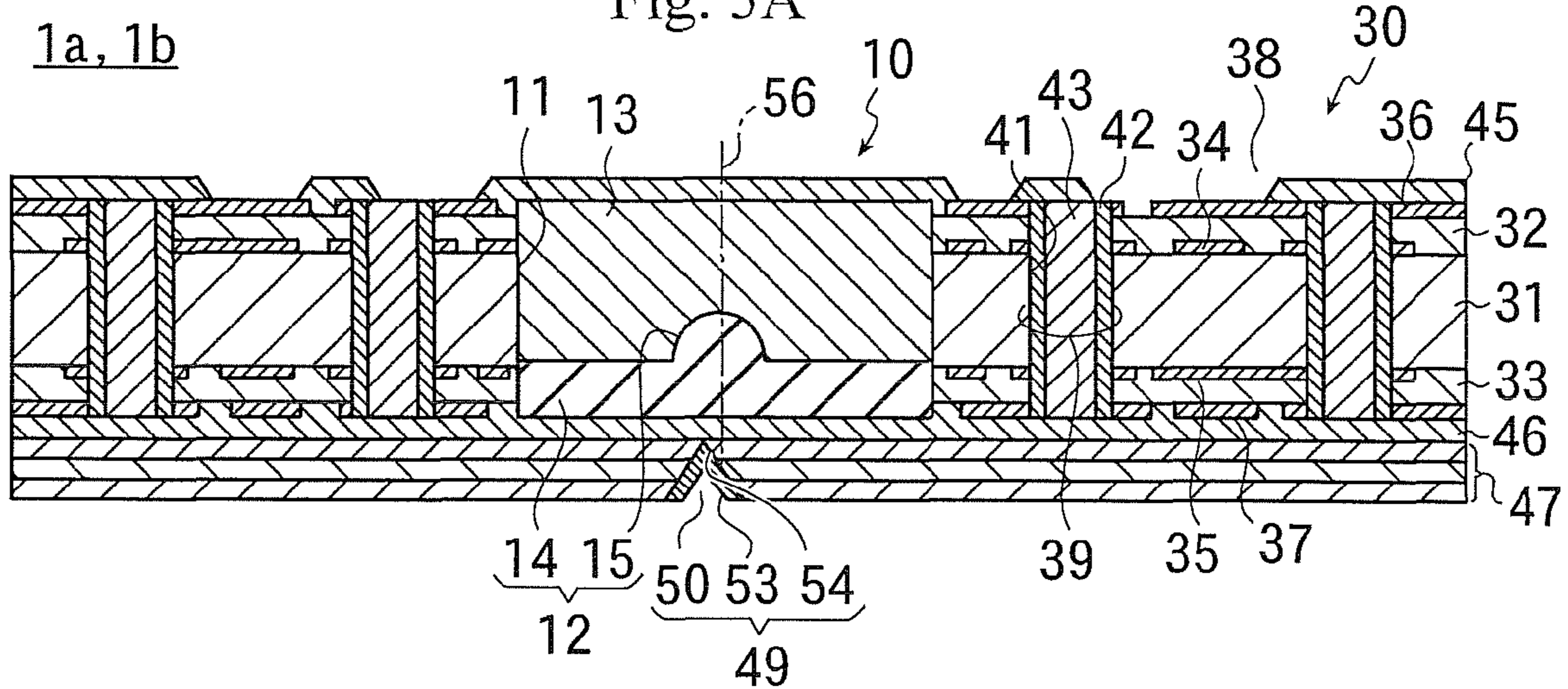


Fig. 5B

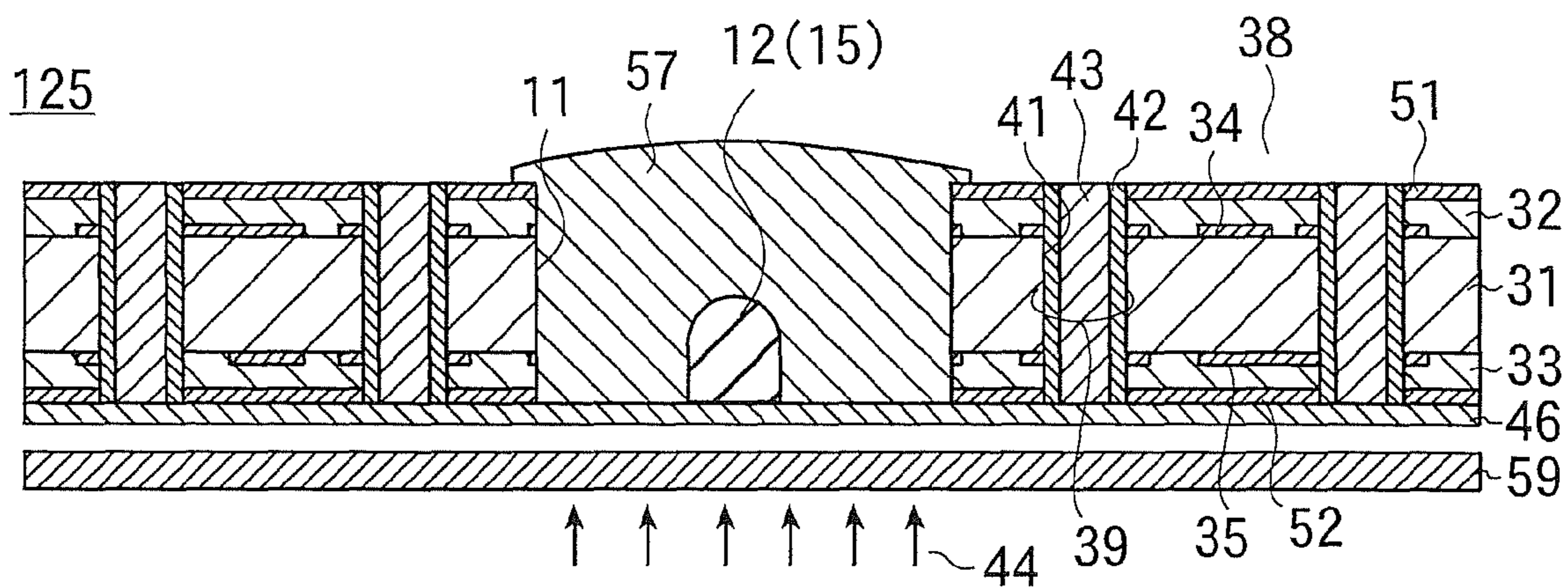


Fig. 6A

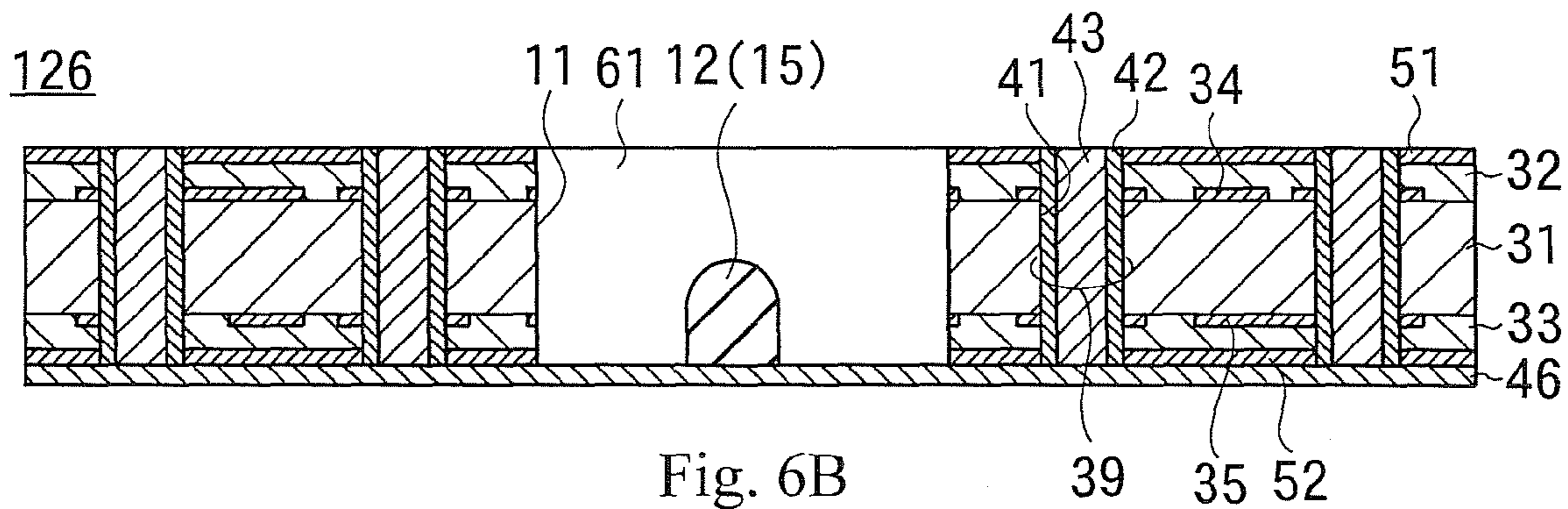


Fig. 6B

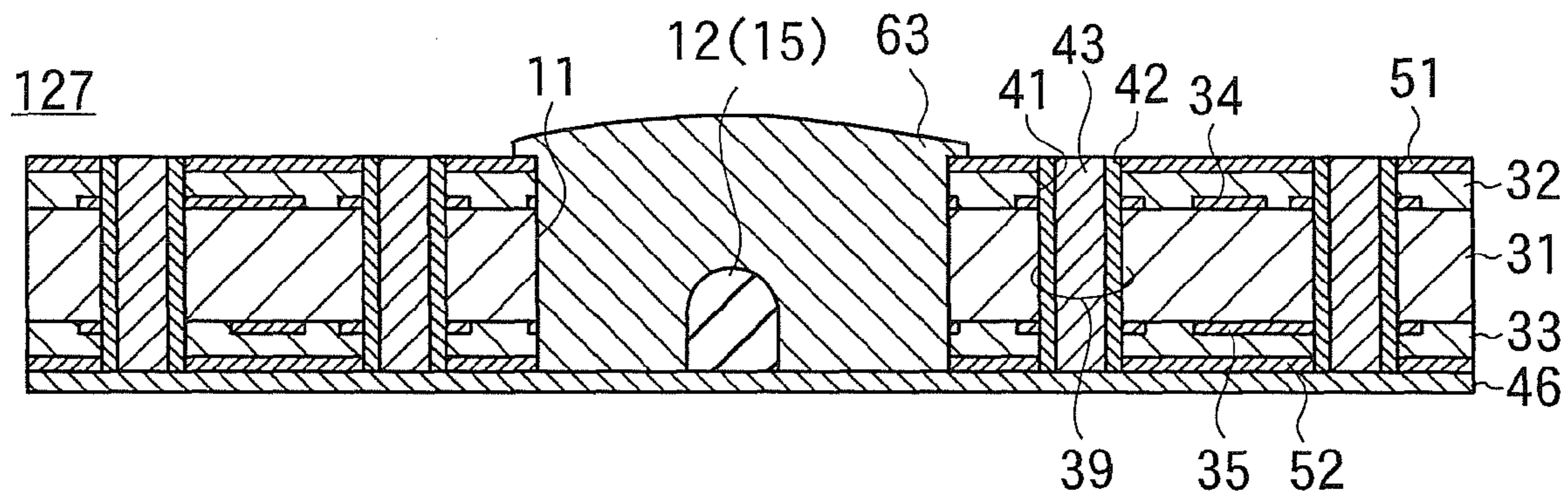
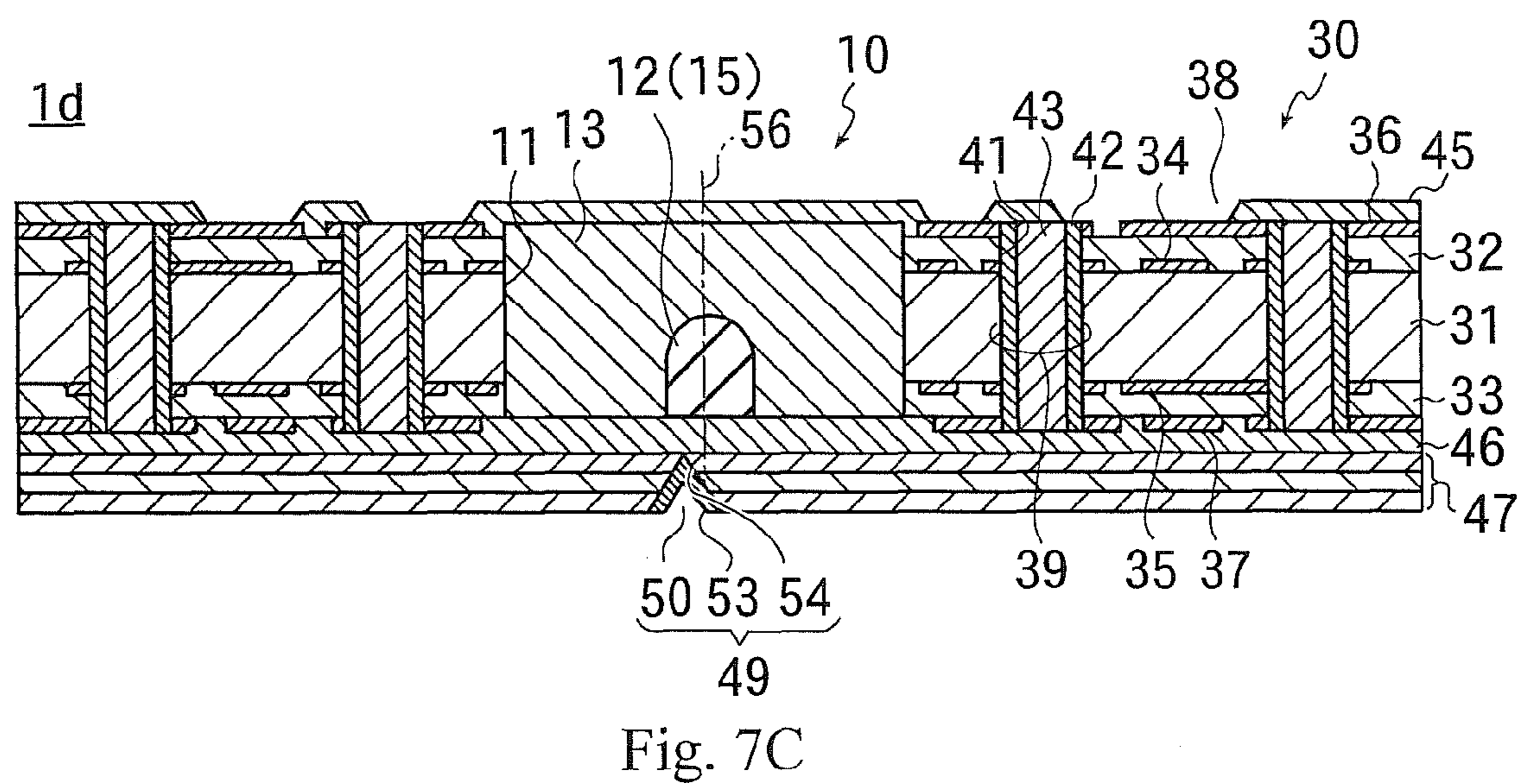
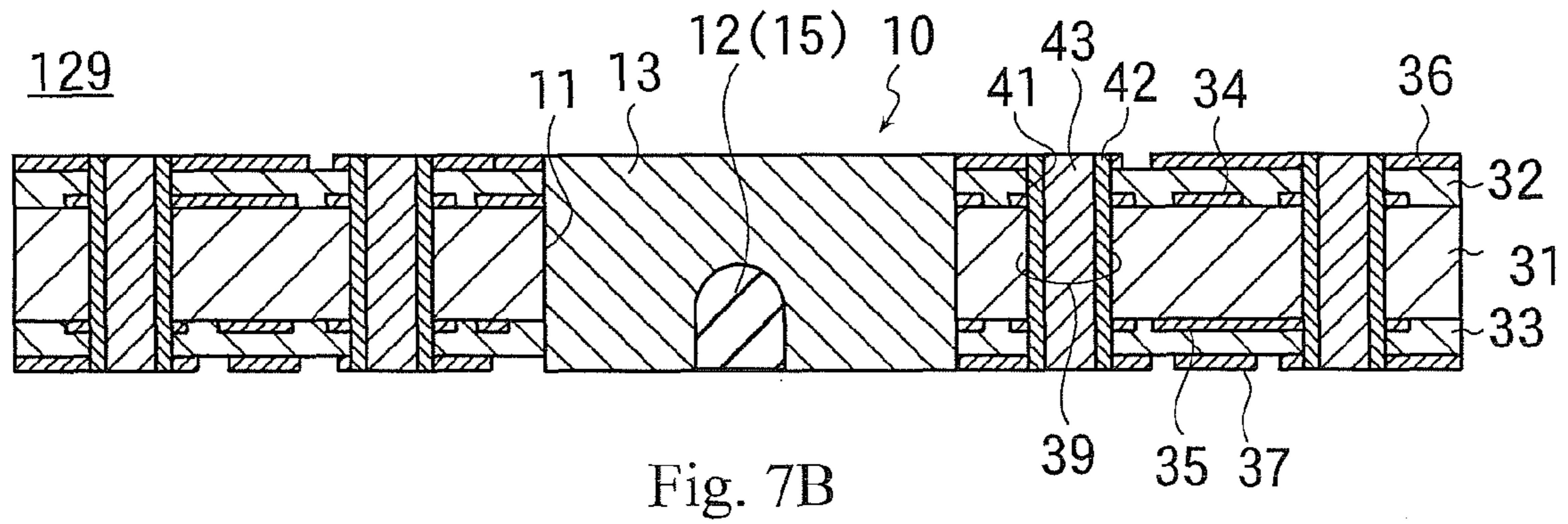
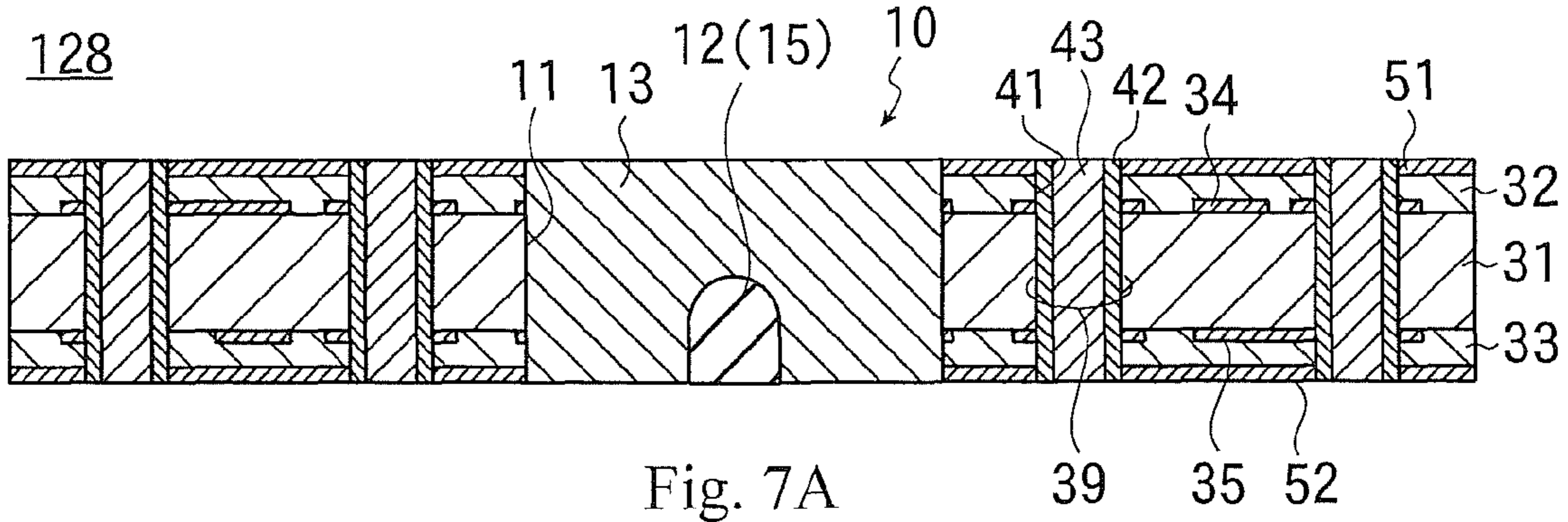
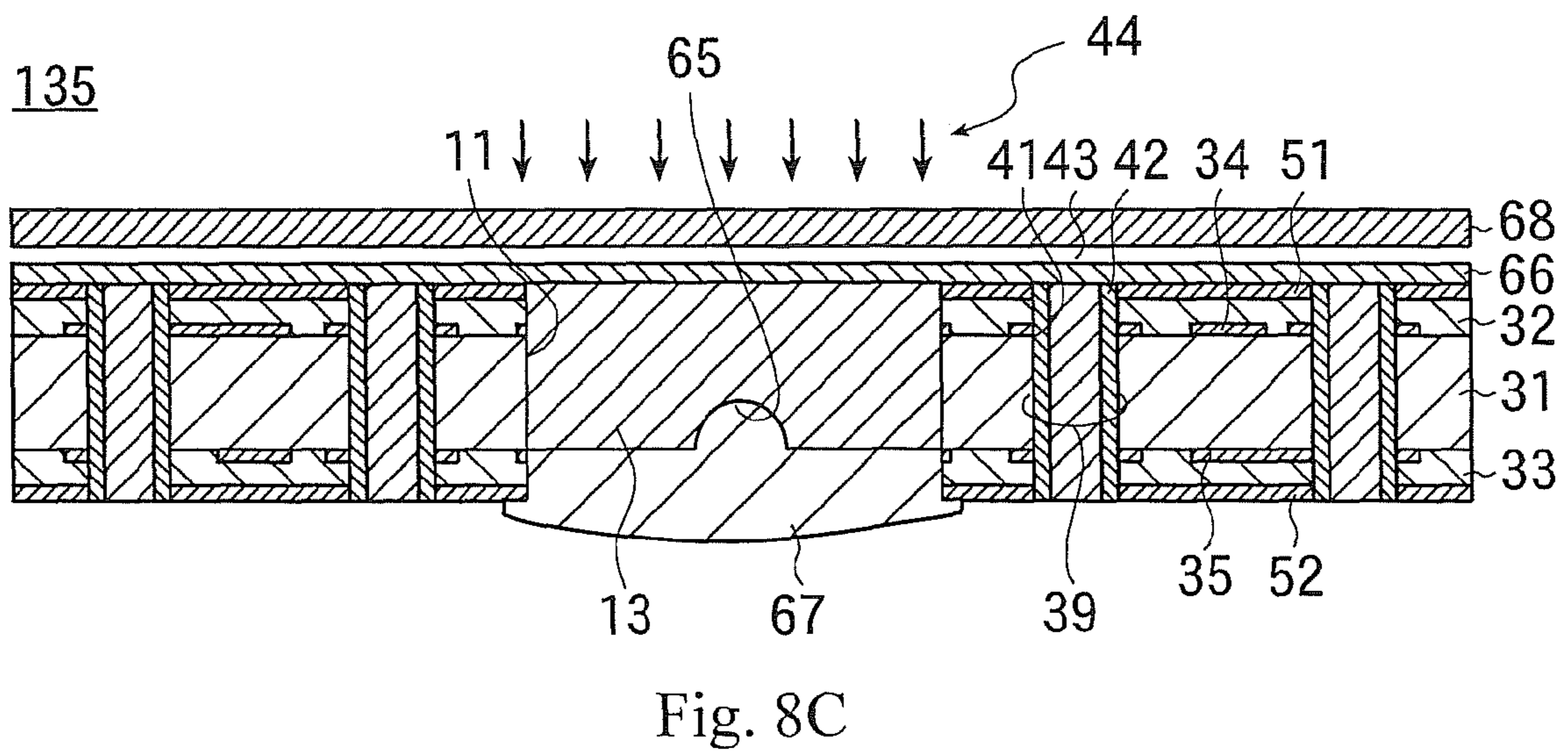
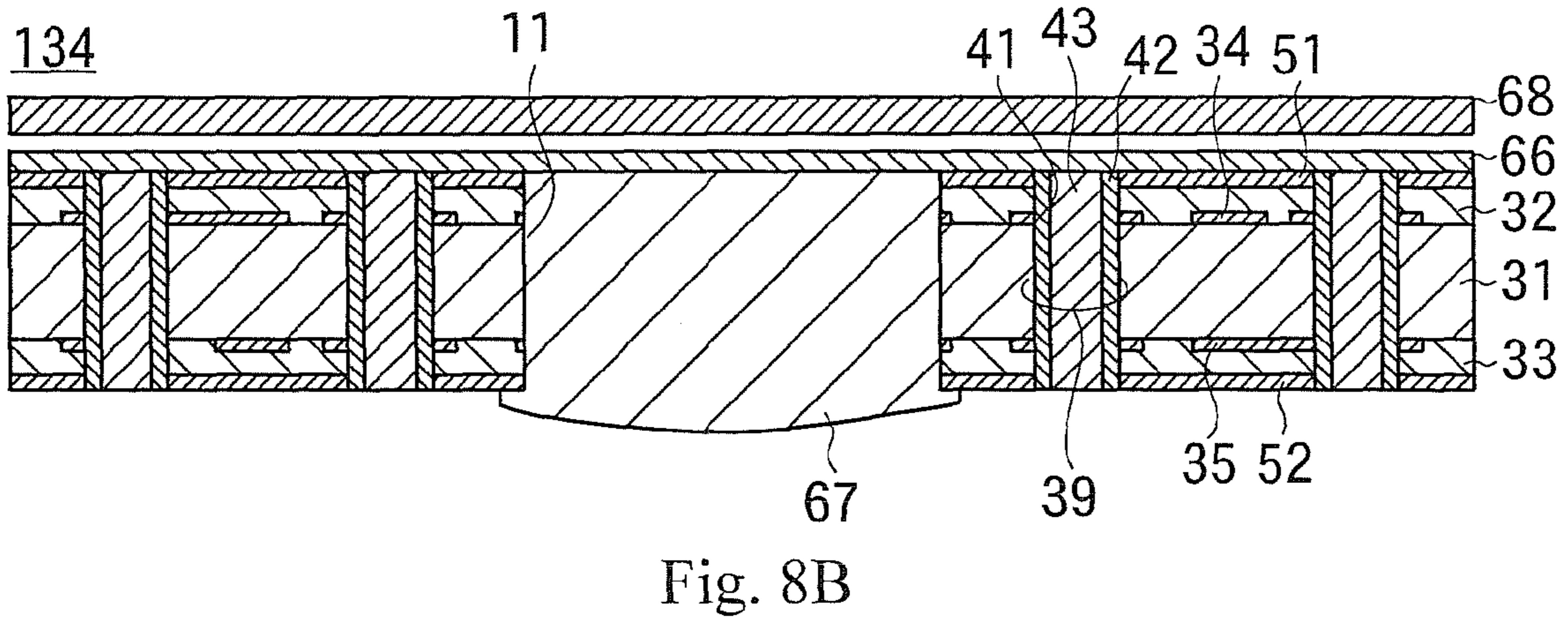
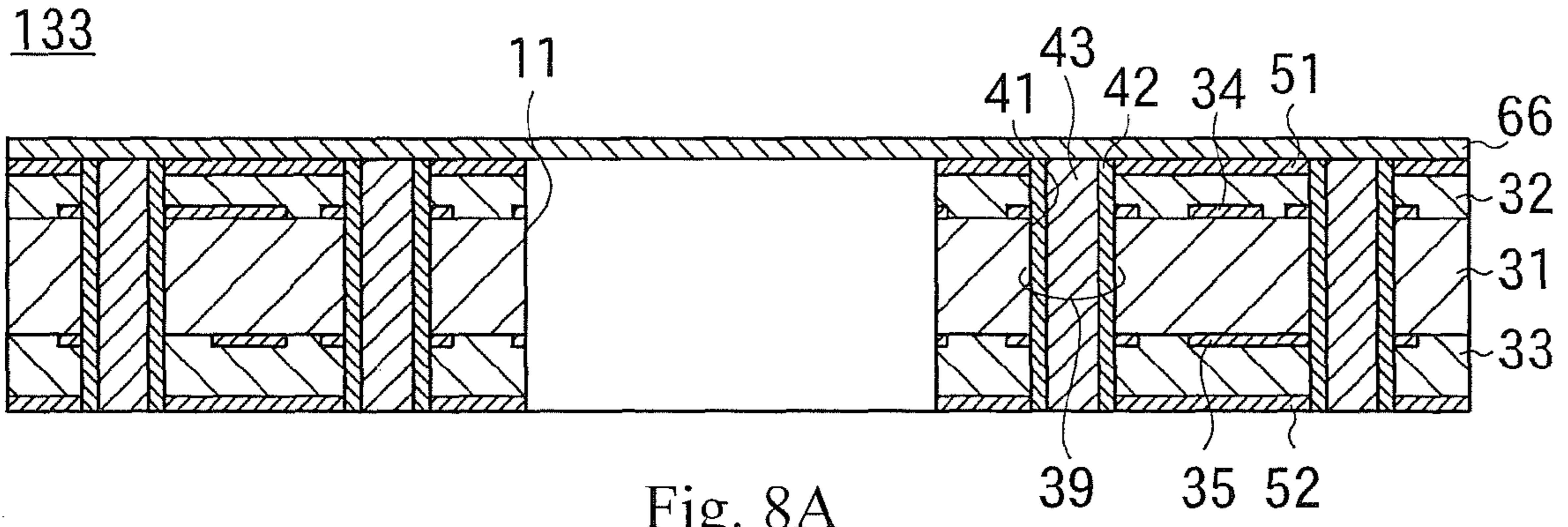


Fig. 6C







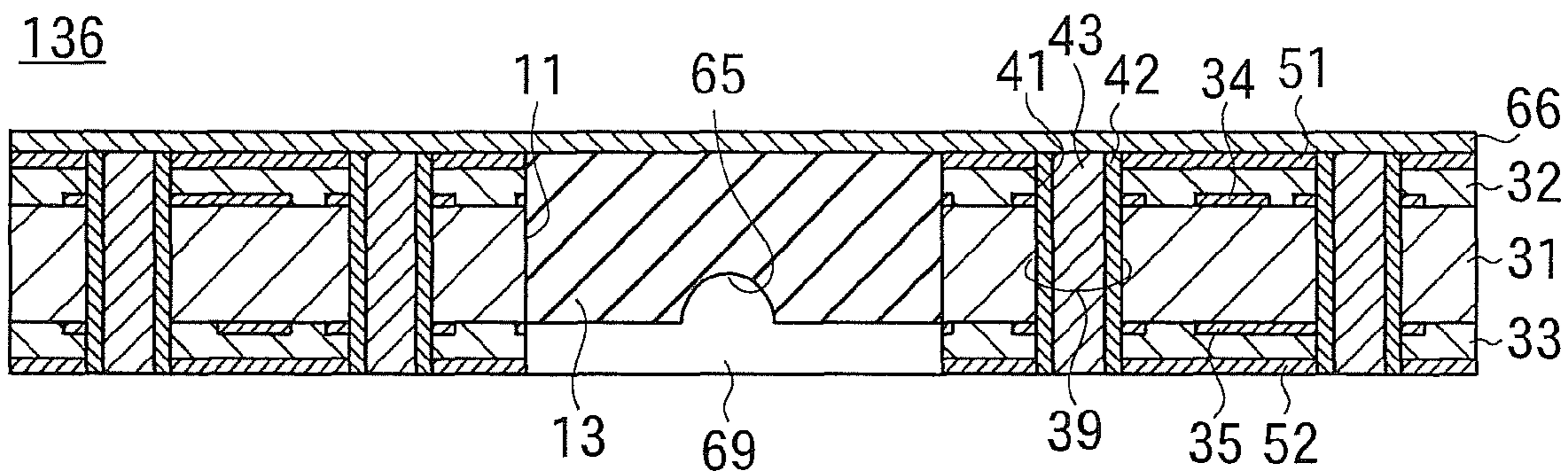


Fig. 9A

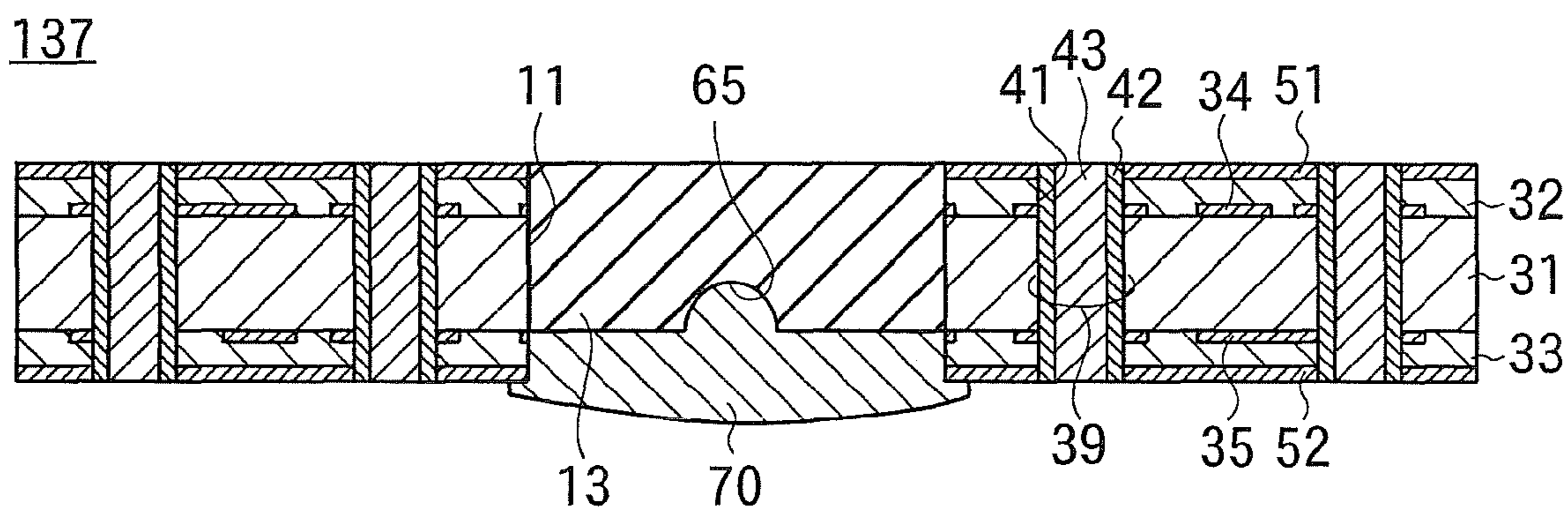


Fig. 9B

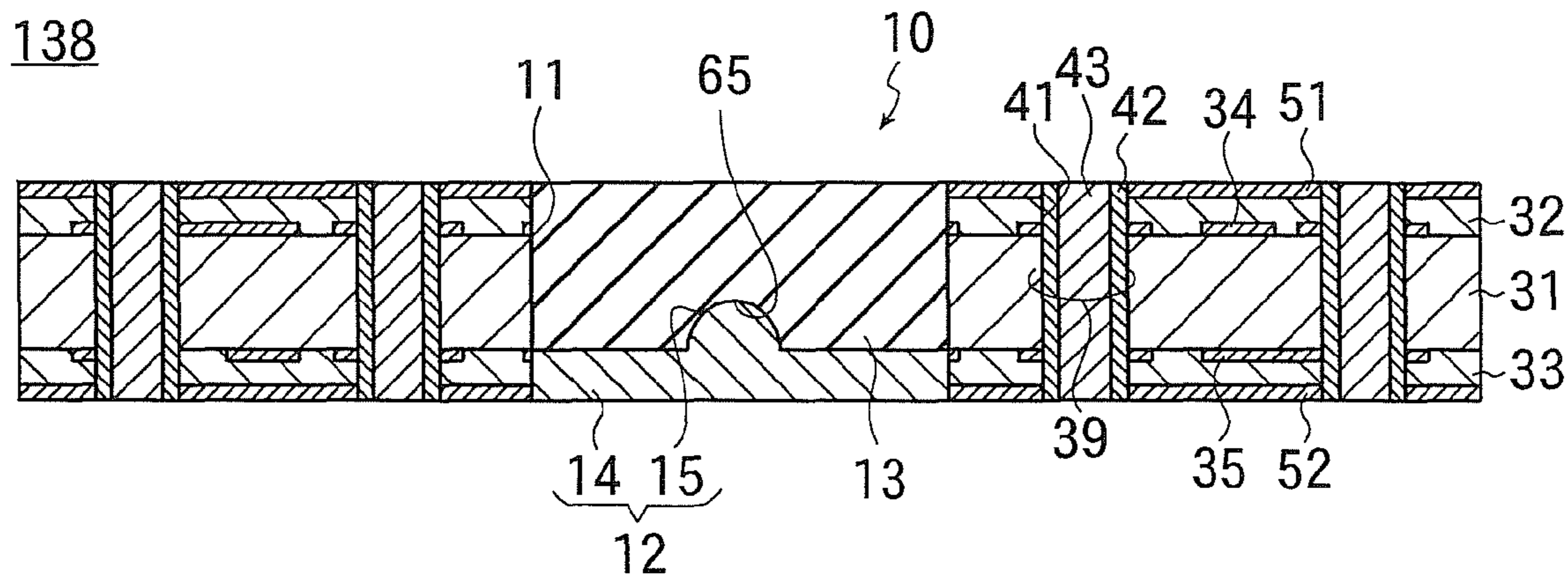


Fig. 9C

2a, 2b

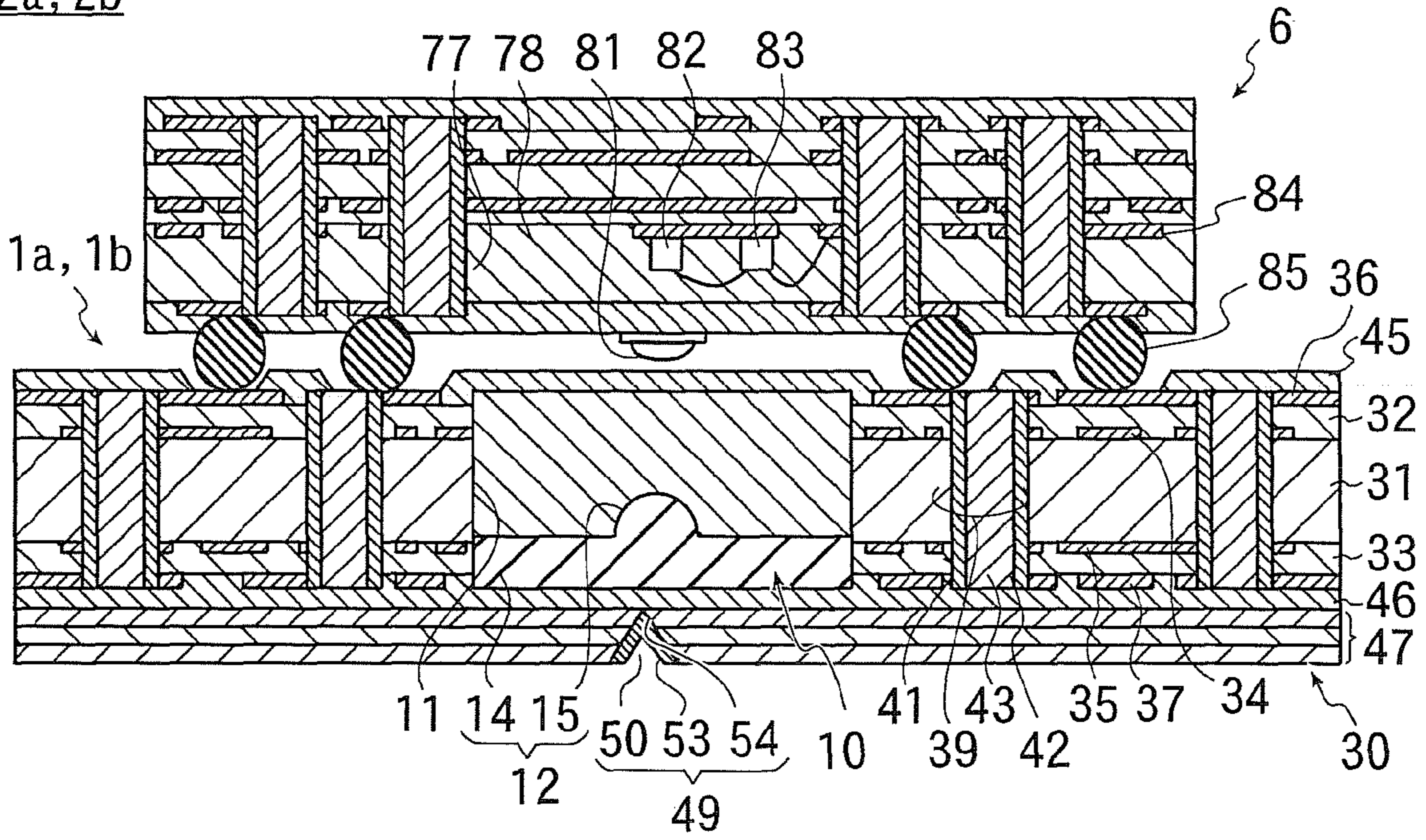


Fig. 10A

3a, 3b

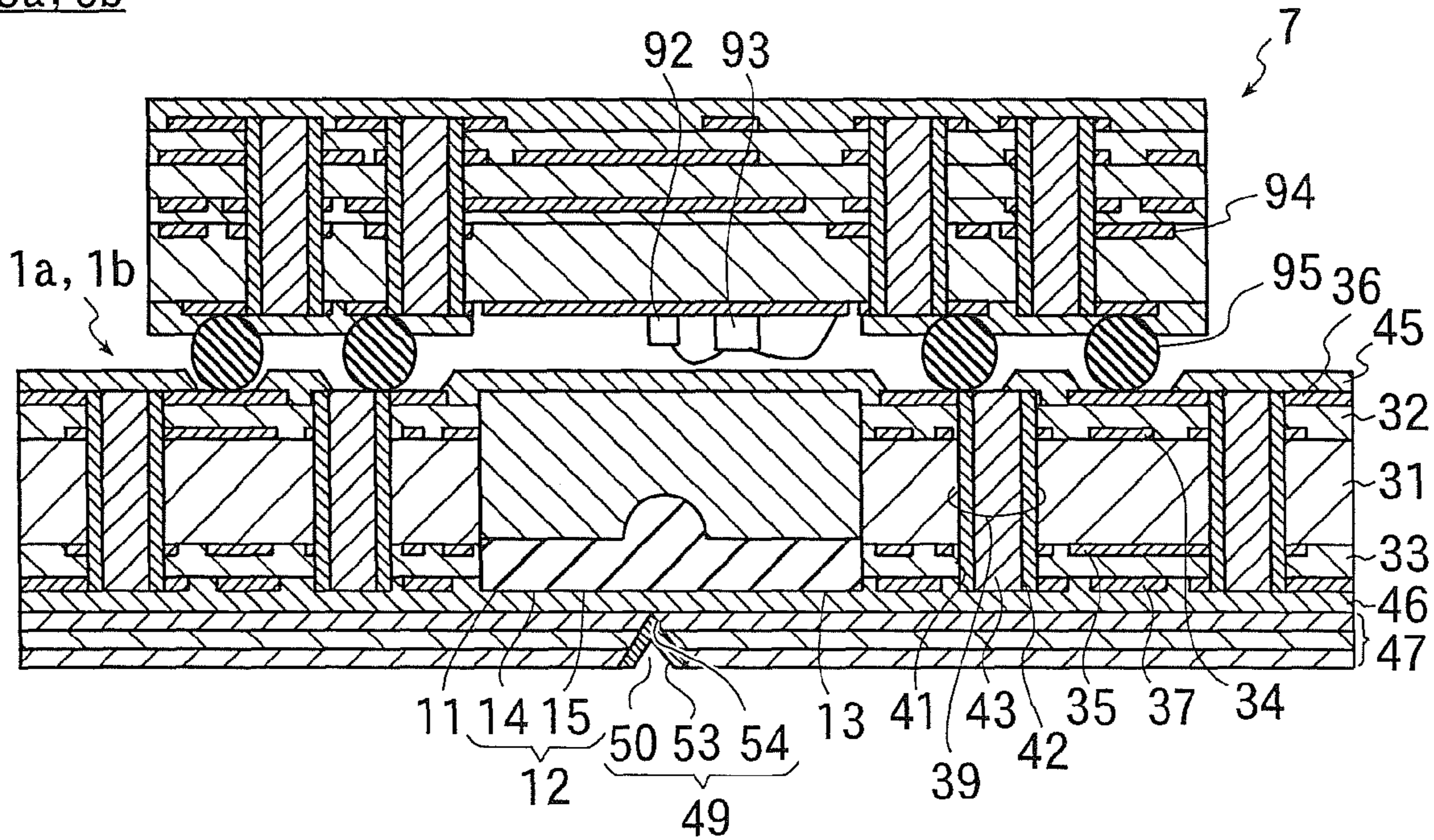


Fig. 10B

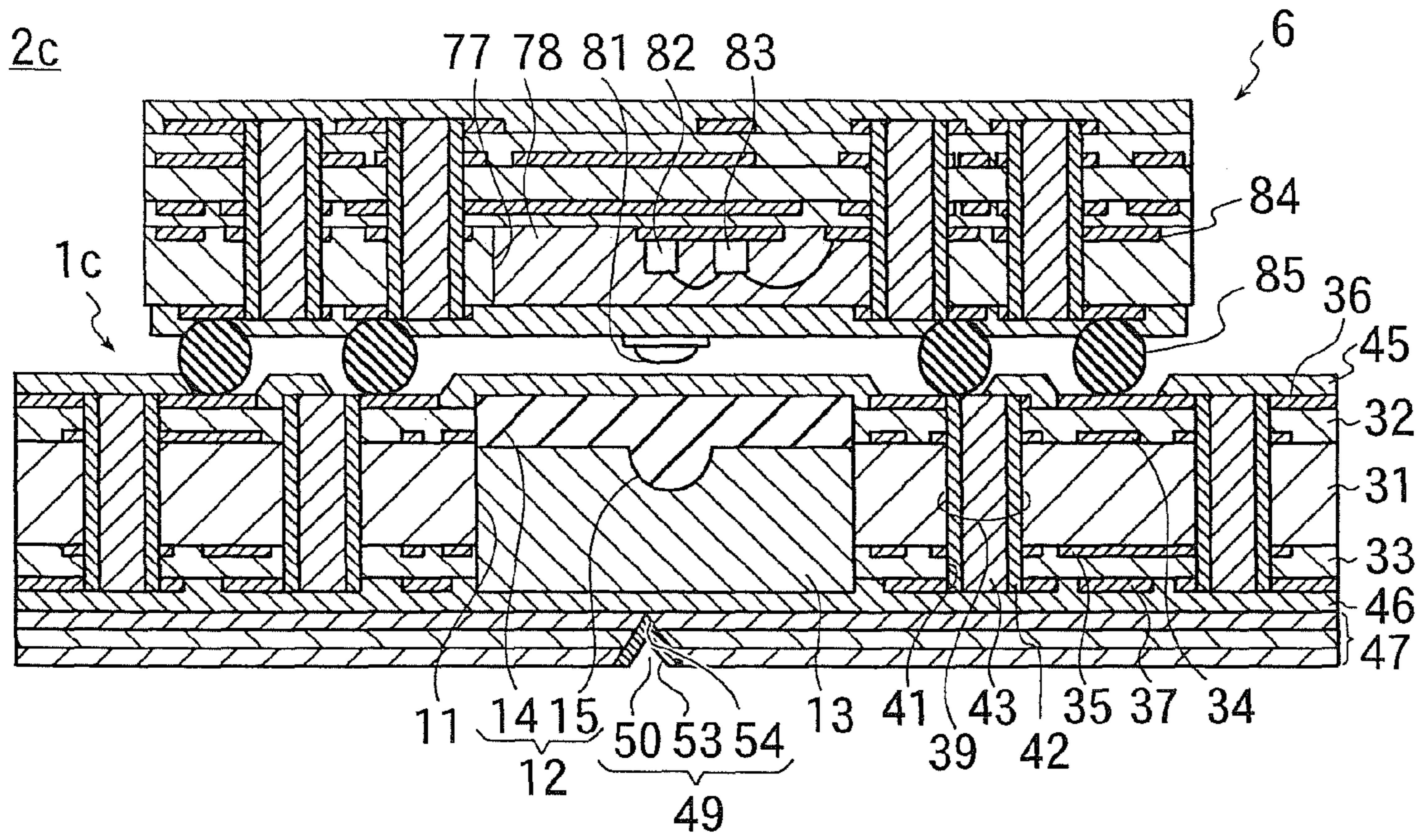


Fig. 11A

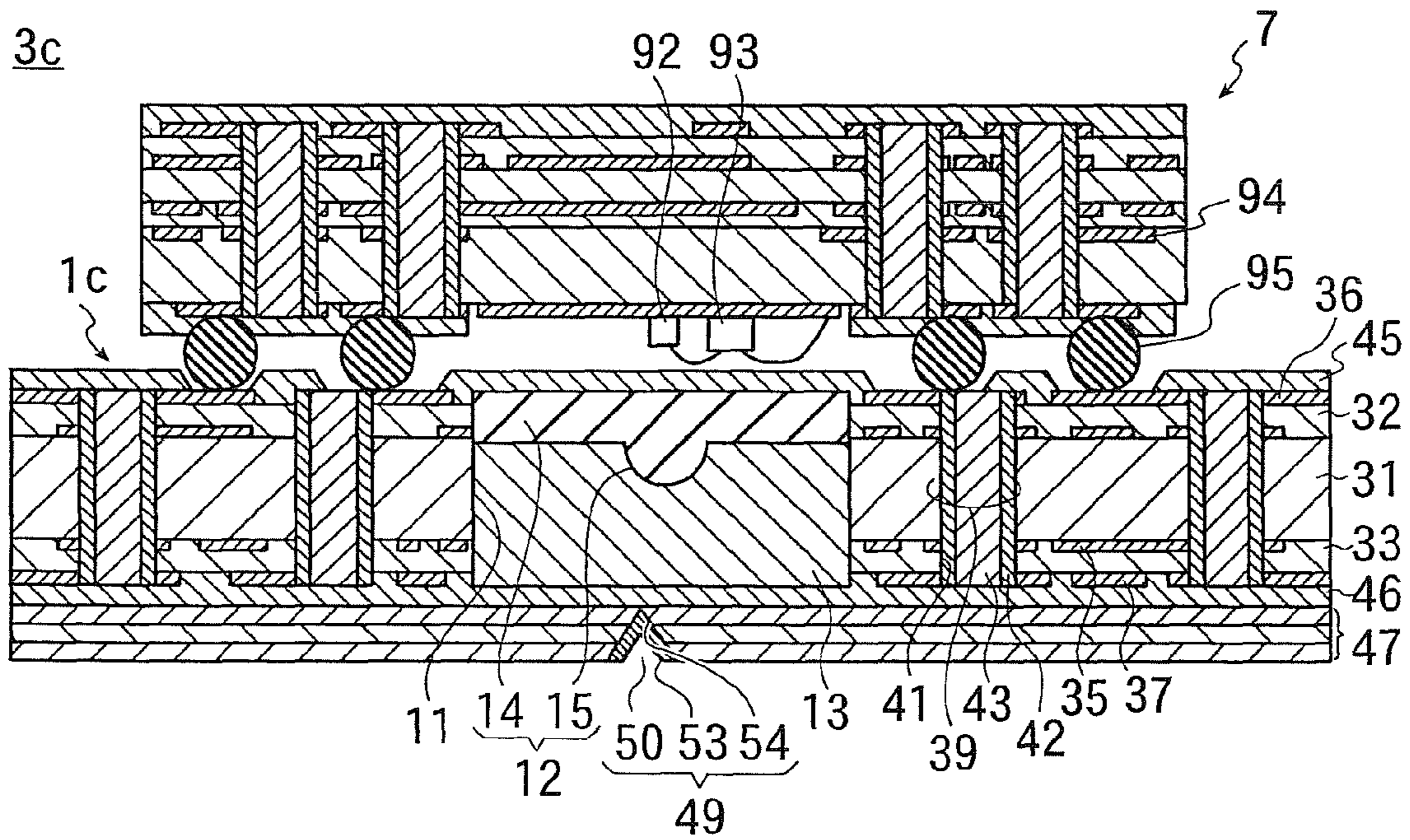


Fig. 11B

58

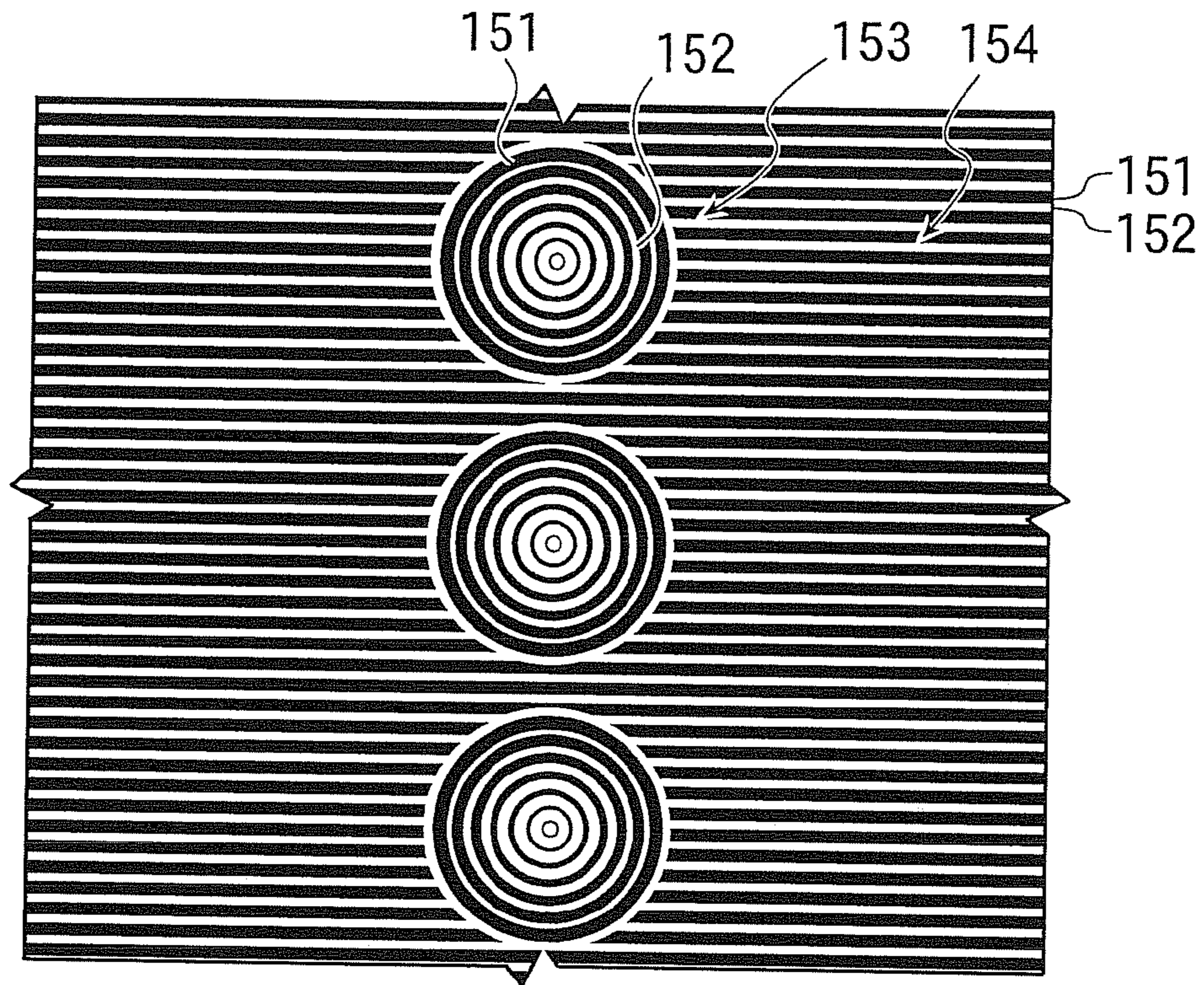


Fig. 12A

59

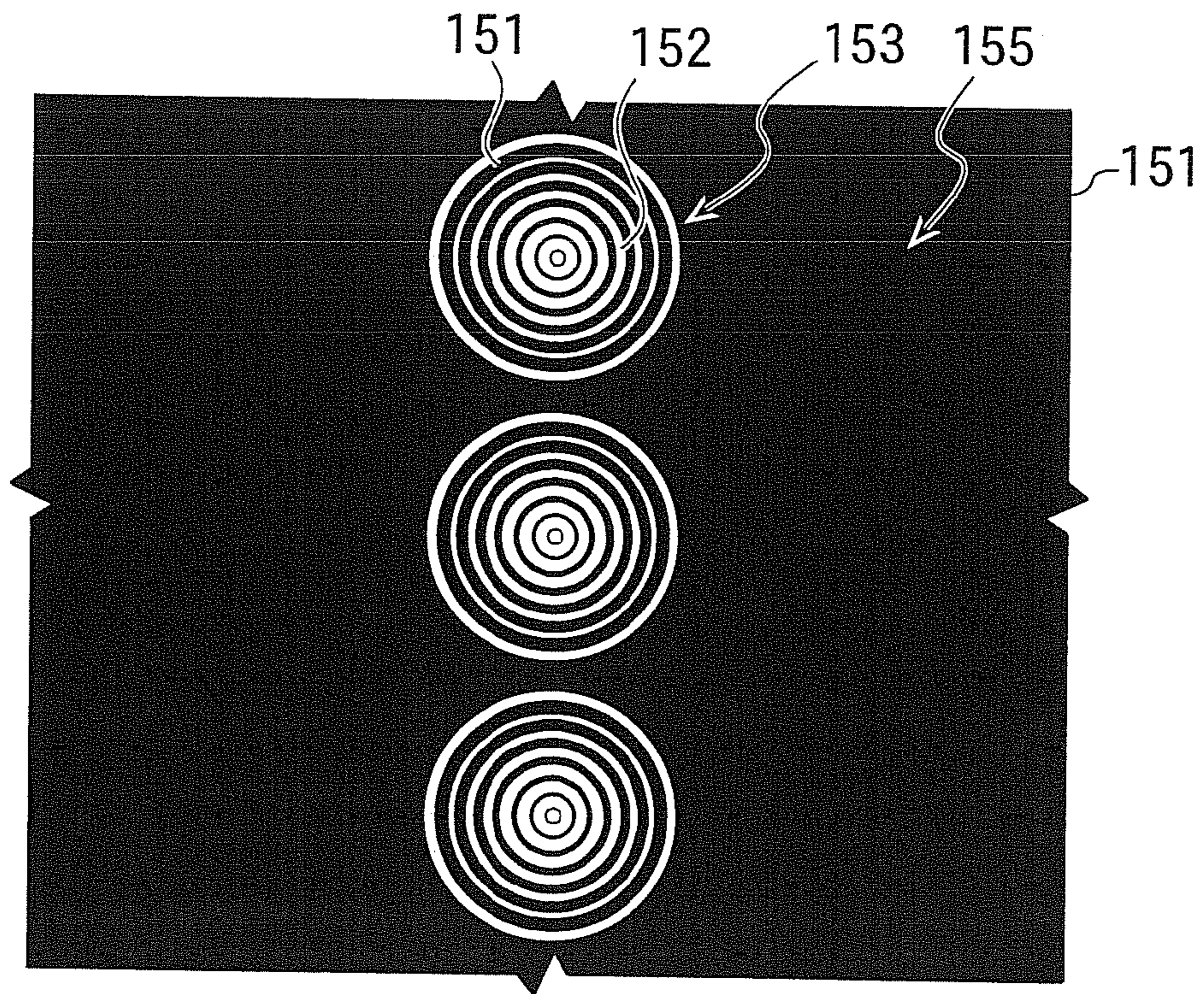


Fig. 12B

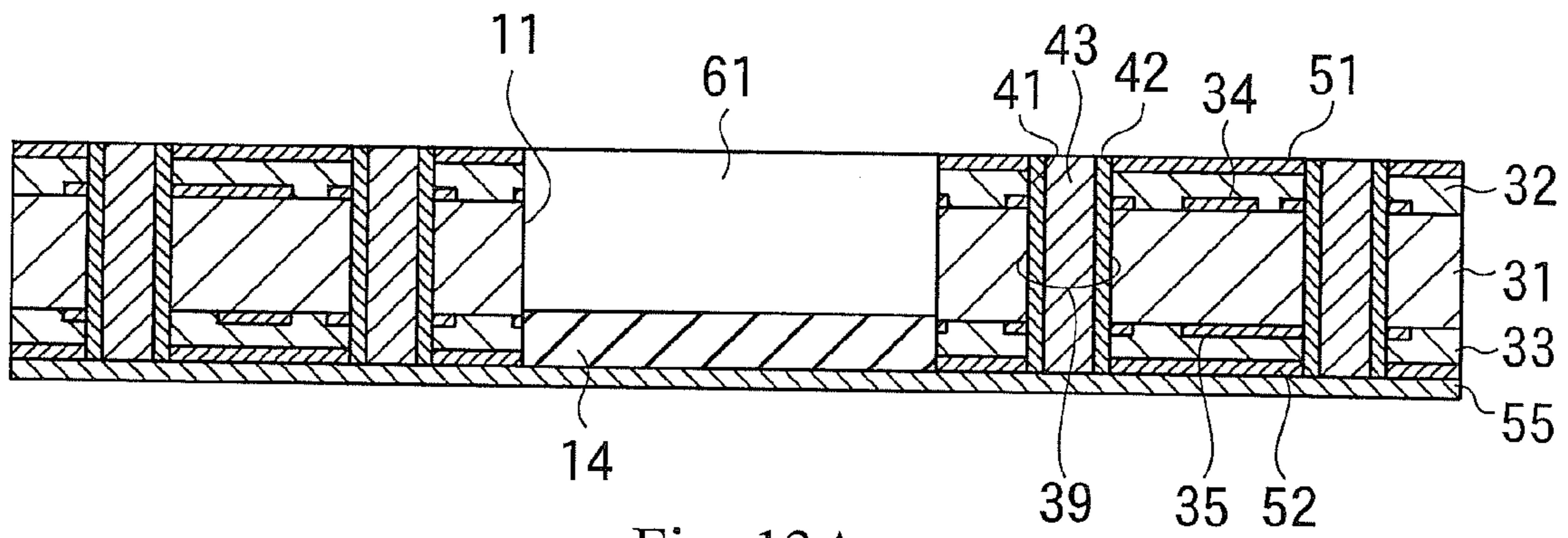


Fig. 13A

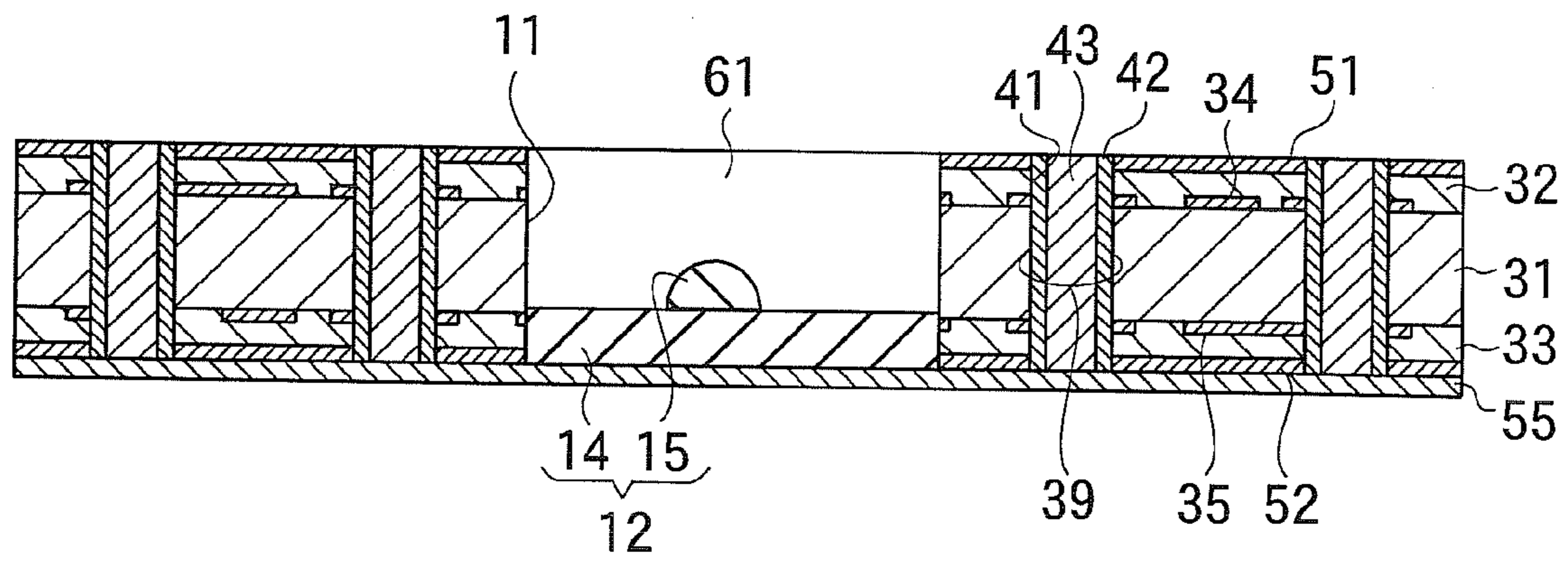


Fig. 13B

**OPTICAL AND ELECTRICAL CIRCUIT  
BOARD AND METHOD OF  
MANUFACTURING THE SAME**

CROSS-REFERENCE TO RELATED  
APPLICATIONS

The present application is a continuation application claiming priority under 35 U.S.C. §120 to International Application No. PCT/JP2007/052990 filed Feb. 19, 2007, which claims priority to Japanese Patent Application No. 2006-066706, filed on Mar. 10, 2006. The contents of these applications are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an optical and electrical circuit board, and a method of manufacturing the optical and electrical circuit board.

2. Discussion of the Background

In recent years, the amount of communication data of the Internet or the like is increasing dramatically, and a technology for realizing high-speed and large capacity communication using an optical signal by converting an electrical signal in a signal processor and an optical signal transmitted through an optical fiber to each other become increasingly important.

An optical and electrical circuit board having a structure that a microlens condensing an optical signal is disposed between an optical signal receiving/transmitting element and an optical waveguide in order to convert an electrical signal and an optical signal to each other, has been proposed.

Methods of forming such a microlens include a method using a mold, a forming method by dropping lens material, a method of forming a lens by heating and softening lens material cylindrical shaped, a method of exposing lens material to exposure light which has passed through a mask. In each of the conventional manufacturing methods, a microlens is formed separately from an optical and electrical circuit board and is mounted on the optical and electrical circuit board, so that the cost of mounting the microlens is high and alignment of the microlens to the substrate is difficult.

A method of forming a microlens using a mask is described in, for example, Japanese Patent Application Laid-open No. 8-286002. The contents of Japanese Patent Application Laid-open No. 8-286002 are incorporated herein by reference in their entirety.

SUMMARY OF THE INVENTION

According to one aspect of the present invention, an optical and electrical circuit board includes a patterned electrical wiring and a micro convex lens. The micro convex lens is provided in at least one hole formed in the optical and electrical circuit board.

According to another aspect of the present invention, a method of manufacturing an optical and electrical circuit board includes filling first photoreactive material into at least one hole which is formed in a substrate having a patterned electrical wiring and which passes through the substrate in a thickness direction thereof. The first photoreactive material is partially exposed from one opening of the hole to form a cured portion and a soluble portion. Then, the soluble portion of the first photoreactive material is dissolved and removed to form a micro convex lens in the hole.

According to further aspect of the present invention, a method of manufacturing an optical and electrical circuit board includes filling second photoreactive material into at least one hole which is formed in a substrate having a patterned electrical wiring and which passes through the substrate in a thickness direction thereof. The second photoreactive material is partially exposed from one opening of the hole to form a cured portion and a soluble portion. Then, the soluble portion of the second photoreactive material is dissolved and removed to form a filling portion having a concave part in the hole. Second filling material having optical transparency and a refractive index higher than a refractive index of the filling portion is filled in the concave part. Then, the second filling material is cured to form a micro convex lens.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the invention and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

FIGS. 1A to 1C illustrate a process of manufacturing the optical and electrical circuit board of a first embodiment of the present invention: FIG. 1A shows a step of forming metal layers, FIG. 1B shows a step of forming a hole, and FIG. 1C shows a step of adhering a supporting film;

FIGS. 2A to 2C illustrate the process of manufacturing the optical and electrical circuit board of the first embodiment of the present invention: FIG. 2A shows a step of filling first photoreactive material, FIG. 2B shows a step of forming micro convex lenses supported by a supporting portion, and FIG. 2C shows a step of removing uncured first photoreactive material;

FIGS. 3A to 3C illustrate the process of manufacturing the optical and electrical circuit board of the first embodiment of the present invention: FIG. 3A shows a step of filling first filling material, FIG. 3B shows a step of curing, and FIG. 3C shows a step of grinding;

FIGS. 4A to 4C illustrate the process of manufacturing the optical and electrical circuit board of the first embodiment of the present invention: FIG. 4A shows a step of patterning metal layers, FIG. 4B shows a step of forming a protection layer, and FIG. 4C shows a step of forming optical waveguides;

FIGS. 5A and 5B illustrate the process of manufacturing the optical and electrical circuit board of the first embodiment of the present invention: FIG. 5A shows a step of forming notches, and FIG. 5B shows a step of forming reflectors;

FIGS. 6A and 6B illustrate a process of manufacturing the optical and electrical circuit board of a variation of the present invention: FIG. 6A shows a step of forming isolated micro convex lenses, FIG. 6B shows a step of removing remained first photoreactive material, and FIG. 6C shows a step of filling first filling material;

FIGS. 7A to 7C illustrate the process of manufacturing the optical and electrical circuit board of the variation of the present invention: FIG. 7A shows a step of removing a supporting film, FIG. 7B shows a step of patterning metal layers, and FIG. 7C shows a step of forming optical waveguides and reflectors;

FIGS. 8A to 8C illustrate a process of manufacturing the optical and electrical circuit board of a second embodiment of the present invention: FIG. 8A shows a step of adhering a supporting film to a side opposite to a side in the case of the first embodiment, FIG. 8B shows a step of filling second

photoreactive material, and FIG. 8C shows a step of forming a filling portion having a depression;

FIGS. 9A to 9C illustrate a process of manufacturing the optical and electrical circuit board of the second embodiment of the present invention: FIG. 9A shows a step of removing uncured second photoreactive material, FIG. 9B shows a step of injecting and curing second filling material, and FIG. 9C shows a step of grinding;

FIG. 10A illustrates the state that an example of an optical-electrical signals conversion substrate is mounted on the optical and electrical circuit board of the first embodiment or the second embodiment, and FIG. 10B illustrates the state that another example of an optical-electrical signals conversion substrate is mounted on the optical and electrical circuit board of the first embodiment or the second embodiment;

FIG. 11A illustrates the state that an example of an optical-electrical signals conversion substrate is mounted on the optical and electrical circuit board of the third embodiment, and FIG. 11B illustrates the state that another example of an optical-electrical signals conversion substrate is mounted on the optical and electrical circuit board of the third embodiment;

FIG. 12A shows an example of a mask for forming micro convex lenses, and FIG. 12B shows another example of a mask for forming micro convex lenses; and

FIGS. 13A and 13B illustrate an example of forming a supporting portion and micro convex lenses by two or more exposure processes.

#### DETAILED DESCRIPTION OF THE EMBODIMENTS

The embodiments will now be described with reference to the accompanying drawings, wherein like reference numerals designate corresponding or identical elements throughout the various drawings.

The reference numeral *1a* in FIG. 5B denotes a first embodiment of an optical and electrical circuit board of the present invention.

An optical and electrical circuit board *1a* has a multi-layer substrate section **30** and a lens section **10**. The multi-layer substrate section **30** is structured in such a manner that one or more layers of substrate, insulating layers, and wiring layers which are electrical wirings are laminated. The multi-layer substrate section **30** has a base layer **31**, patterned wiring layers **34** and **35** are disposed on the top surface and back surface of the base layer **31**, insulating layers **32** and **33** are disposed so as to cover the wiring layers **34** and **35**, respectively, on the top surface and back surface of the base layer **31**, and patterned wiring layers **36** and **37** are disposed on the surfaces of the insulating layers **32** and **33**, respectively. The wiring layers **34** to **37** of different layers are separated from each other by the base layer **31** and the insulating layers **32** and **33**.

In this embodiment, only one of the insulating layers **32** and **33** and only one of the wiring layers **34** and **35** are formed on each side of the base layer **31**, and only two of the wiring layers **34** to **37** including wiring layers **36** and **37** on the insulating layers **32** and **33** are formed on each side of the base layer **31**. However, a multi-layer substrate having three or more layers on one side including insulating layers and wiring layer further laminated is also included in the multi-layer substrate section **30** of the present invention.

In addition, on the surfaces of the outermost wiring layers **36** and **37**, protection layers **45**, **46** (also known as solder resist layers) are disposed so as to cover the wiring layers **36**

and **37**, respectively, in order that the optical and electrical circuit board *1a* is not shorted to external electric components.

For the base layer **31** and the insulating layers **32** and **33**, ceramic may be used in addition to resin such as epoxy. For the wiring layers **34** to **37**, patterned metal films such as copper films can be used.

In the multi-layer substrate section **30**, through-holes **41** penetrating it in the thickness direction thereof are formed, and conductive interlayer connecting layer **42** composed of electroless plating layer is formed on the inner peripheral surface of the through-hole **41**. The inside of the through-hole **41**, that is, space surrounded by the interlayer connecting layer **42**, is filled with resin filler **43**.

The interlayer connecting layer **42** is in contact with part of wiring layers **34** to **37** and mutually connect the wiring layers **34** to **37** located in different layers so that electrical signal is transmitted between the wiring layers **34** and **37** in different layers through the interfacial connecting layers **42**.

Next, a hole **11** having a diameter larger than that of the through-hole **41** is formed in the multi-layer substrate section **30**, and the lens section **10** is disposed in the hole **11**.

The lens section **10** has an optical condensing portion **12** for condensing light and a filling portion **13** which fills a portion other than the optical condensing portion **12** inside the hole **11**.

The optical condensing portion **12** is disposed at an end of the hole **11**, and the filling portion **13** is located on the opposite side of the optical condensing portion **12** in the hole **11**.

The optical condensing portion **12** has one or more micro convex lenses **15** and a supporting portion **14** located on side faces of the micro convex lenses **15**.

The micro convex lenses **15** are located apart from the inner peripheral side surface of the hole **11**, and the supporting portion **14** is in contact with the inner peripheral side surface of the hole **11** and is fixed to the contact portion, so that each of the micro convex lenses **15** is fixed to the inner peripheral side surface of the hole **11** through the supporting portion **14**.

Furthermore, the optical condensing portion **12** and the filling portion **13** are in close contact with each other, and the filling portion is in contact with the inner peripheral side surface of the hole **11** and is fixed to the contact portion. The micro convex lenses **15** are in close contact with the filling portion **13** and are fixed to the close contact portion, so that the micro convex lenses **15** are also fixed to the inner peripheral side surface of the hole **11** through the filling portion **13**.

On a surface of the multi-layer substrate section **30**, an optical wave guide **47** is extended for each of the micro convex lenses **15** in such a manner that the optical waveguides **47** cross the intersection position of optical axis **56** of the micro convex lens **15**.

In positions where the optical waveguides **47** intersect the optical axes **56** of the micro convex lenses **15**, a reflector **49** is provided for each of the optical waveguides **47**.

The optical waveguides **47** are located in the planes which are parallel to each other including the same plane. When an optical signal is transmitted in each of optical waveguide **47** and enters a reflector **49**, the optical signal is reflected from a direction substantially perpendicular to the plane where the optical waveguide **47** is located. In contrast, when an optical signal enters a reflector **49** in a direction substantially perpendicular to a plane where the optical wave guide **47** is located, the optical signal is reflected in a direction substantially perpendicular in order to guide the optical signal to the inside of the optical waveguide **47**.

The refractive index of a constituent material of the optical condensing portion **12**, particularly the micro convex lenses



**15** is larger than that of a constituent material of the filling portion **13**, and the micro convex lenses **15** have a shape near a hemisphere which is thick in the middle and thinner nearer the outer periphery than the middle. Portion swelling thick is in close contact with the filling portion. Thus, both of an optical signal entering the filling portion **13** through the micro convex lens **15** and an optical signal entering the micro convex lens **15** through the filling portion **13** are condensed.

The micro convex lens **15** is located in the traveling direction of an optical signal reflected in a direction substantially perpendicular to a plane where the optical waveguide **47** is located, and the reflected optical signal enters the micro convex lens **15** in parallel with the optical axis **56**, is condensed, and is released to the outside of the multi-layer substrate section **30** through the filling portion **13**.

In contrast, an optical signal passes through the filling portion **13** and enters a micro convex lens **15** in parallel with the optical axis **56**. In the traveling direction of the optical signal condensed by the micro convex lens **15**, the reflector **49** is located. When the condensed optical signal enters the reflector **49** in a direction substantially perpendicular to a plane where the optical waveguide **47** is located, it is reflected almost vertically and guided into the optical waveguide **47**.

On the optical and electrical circuit board **1a** of the present invention (and below-mentioned optical and electrical circuit boards **1b** to **1d**), various electrical or optical components and substrates can be mounted.

The reference numerals **2a**, **3a** in FIGS. **10A** and **10B** denote an optical and electrical circuit board on which an optical-electrical signals conversion substrate **6**, **7** is mounted.

The optical-electrical signals conversion substrate **6**, **7** has light-emitting/receiving elements **92** and **92**, respectively. Inside the optical-electrical signals conversion substrate **6**, **7** and/or on a surface thereof, patterned wiring layers **94** and **94** are disposed. The light-emitting/receiving elements **82** and **92** are connected with the wiring layers **84** and **94**, and electrical signals can be transmitted between the light-emitting/receiving elements **82** and **92** and electronic components such as driver ICs (or amplifier ICs) **83** and **93**.

First, in FIG. **10A**, the optical-electrical signals conversion substrate **6** has a recess **77** inside thereof, and the light-emitting/receiving elements **82** are disposed in the recess **77**.

The optical-electrical signals conversion substrate **6** is disposed in such a manner that the light-receiving elements **82** are located on the extension lines of the optical axes **56** of the micro convex lenses **15**.

The optical-electrical signals conversion substrate **6** has convex lenses **81**, which are disposed just above the light-emitting/receiving elements **82**. Inside of the recess **77** is filled with filling material **78** transparent to an optical signal.

When a light-emitting/receiving element **82** operates as a light-receiving element, an optical signal which has been transmitted in an optical waveguide **47** in the optical and electrical circuit board **1a** and reflected by the reflector **49** is condensed by an optical condensing portion **12** and a convex lens **81**, enters the light-emitting/receiving element **82**, and then is converted to an electrical signal.

When a light-emitting/receiving element **82** operates as a light-emitting element, an electrical signal input from the wiring layer **84** is converted to an optical signal and transmitted by the light-emitting/receiving element **82**. The optical signal output from the light-emitting/receiving element **82** is condensed by a convex lens **81** and the optical condensing portion **12** and reflected by the reflector **49** to be guided into the optical waveguide **47**.

A micro convex lens **15** is disposed for each of the light-emitting/receiving elements **82**, and an optical signal transmitted from each of the light-emitting/receiving elements **82** is condensed by the micro convex lens **15**.

The optical-electrical signals conversion substrate **7** in FIG. **10B** has no depression **77** or convex lens **81**, and light-emitting/receiving elements **92** and driver ICs **93** are exposed on a surface thereof. However, operations of transmitting and receiving an optical signal are equivalent to those in the case of FIG. **10A**.

The wiring layer **36** of the optical and electrical circuit board **1a** is electrically connected with the wiring layers **84**, **94** of the optical-electrical signals conversion substrate **67** through conductive bumps **85**, **95**. Between the optical-electrical signals conversion substrate **6**, **7** and the optical and electrical circuit board **1a**, an optical signal is transmitted unidirectionally or bi-directionally through the lens section **10**, but an electrical signal is transmitted unidirectionally or bi-directionally through the bumps **85**, **95**.

Protection layers **45** and **46** are disposed on the surface of the optical and electrical circuit board **1a** and between the lens section **10** and the optical waveguides **47**, and the protection layers **45**, **46** are transparent to an optical signal, thus not interfering with transmission of an optical signal.

Furthermore, electronic components such as semiconductor elements and capacitors may also be mounted on the optical and electrical circuit board **1a** in order to constitute electronic circuits.

The process of manufacturing an optical and electrical circuit board **1a** as described above will be described.

First, as shown in FIG. **1A**, an object **101** to be processed having wiring layers **34** and **35** and insulating layers **32** and **33** disposed in this order on both sides of a base layer **31** and metal layers **51** and **52** disposed on the surfaces of the insulating layers **32** and **33** is prepared. FIG. **1A** and below-mentioned figures are partial cross-sectional views.

In the object **101** to be processed of FIG. **1A**, through-holes **41** have been previously bored in predetermined locations, interlayer connecting layers **42** have been disposed on the inner peripheral side surfaces of the through-holes **41**, and resin filler **43** is disposed in spaces surrounded by the interlayer connecting layers **42**.

The through-holes **41** also penetrate metal layers **51** and **52**, and the interlayer connecting layers **42** are in contact and electrically connected with the metal layers **51** and **52** exposed in the through-holes **41** at the upper and lower ends of the through-holes **41**. Therefore, as described later, when the metal layers **51** and **52** are patterned to form wiring layers **36** and **37**, the interlayer connecting layers **42** and the wiring layers **36** and **37** which are in contact therewith, are electrically connected with each other.

The through-holes **41** also penetrate the wiring layers **34** and **35** on the base layer **31**, and as similar to the case of the metal layers **51** and **52**, the interlayer connecting layers **42** are in contact and electrically connected with the wiring layers **34** and **35** exposed to the inner peripheral surfaces of the through-holes **41**. As a result, the wiring layers **34** to **37** in different layers are electrically connected with one another through the interlayer connecting layers **42**.

Next, as shown in FIG. **1B**, a large-diameter hole **11** penetrating the object **101** to be processed in the thickness direction thereof is formed.

In an object **102** to be processed in this state, both ends of the hole **11** are opened. Next, as shown in FIG. **1C**, when a supporting film **55** is adhered on one side of a substrate **102** to be processed, one end of the hole **11** is closed with the sup-

porting film **55**, and a substrate **103** to be processed having a vessel-like space opened at the other end is obtained.

In advance, first photoreactive material made of liquid photo-curing material which becomes the material of micro convex lenses **15** has been prepared. The object **103** to be processed is disposed in such a manner that the supporting film **55** faces vertically downward and the open end of the hole **11** faces vertically upward, and liquid first photoreactive material is injected into the hole **11**. For the first photoreactive material and below-mentioned second photoreactive material, organic material is used herein, but inorganic material, photo-curing material, or photodissolution material may be used. Furthermore, also for the first and second filling material, organic material is used, but inorganic material may be used.

The reference numeral **104** in FIG. 2A denotes an object to be processed in the above state. Since the bottom face of the hole **11** is closed with the supporting film **55** which is fluid-tight, the first photoreactive material **57** does not leak from the inside of the hole **11**.

A mask **58** is disposed under the object **104** to be processed and near the supporting film **55**, and exposure light **44** is irradiated to the mask **58** as shown in FIG. 2B.

Since the mask **58** has light-shielding portions described later so as to partially pass the exposure light **44**, and the supporting film **55** is transparent to the exposure light **44**, the exposure light **44** which has passed through the mask **58** and the supporting film **55** enters the first photoreactive material **57**.

The first photoreactive material **57** is resin cured when irradiated with the exposure light **44**. The exposure light **44** having an irradiation shape corresponding to the pattern of the mask **58** is irradiated, so that the first photoreactive material **57** is cured to form an optical condensing portion **12** constituted by the cured portion corresponding to the pattern of the mask **58**.

The reference numeral **105** in FIG. 2B denotes an object to be processed in the state that the optical condensing portion **12** has been formed.

In the present invention, the exposure light is ultraviolet light, visible light, electron beams or the like and widely includes electromagnetic wave and particle beams which cure the first photoreactive material (or below-mentioned second photoreactive material) to form a shape corresponding to the pattern of a mask.

The mask **58** used in this embodiment is a pattern as shown in FIG. 12A and has light-shielding portions **151** shielding the exposure light **44** arranged in a predetermined pattern on a glass substrate. There are light-passing portions **152** where the exposure light **44** passes through, between the light-shielding portions **151**.

The mask **58** has a plurality of lens patterns **153** having the circular light-shielding portions **151** and the circular light-passing portions **152** arranged alternately and concentrically, and a light attenuation pattern **154** which is arranged around each of the lens patterns and has linear light-shielding portions **151** and linear light-passing portions **152** arranged alternately.

The area ratio of the light-passing portions **152** to the light-shielding portions **151** in the light attenuation pattern **154** of the mask **58** is set to be less than the area ratio of the light-passing portions **152** to the light-shielding portions **151** in the lens patterns **153** of the mask **53**, so that the amount of exposure light **44** which has passed through the light attenuation pattern **154** is less than the amount of exposure light **44** which is passed through the lens patterns **153**.

In the lens patterns **153** of the mask **58**, the widths of the light-passing portions **152** are set to be larger nearer to the centers of concentric circles, and the widths of the light-shielding portions are set to be larger nearer to the outermost periphery of the concentric circles. Thus, the area ratio of the light-passing portions **152** to the light-shielding portions **151** in the lens patterns **153** becomes larger nearer to the centers of the concentric circles and smaller nearer to the outer peripheries of the concentric circles.

According to the area ratio described above, the amount of exposure light **44** which has passed through the mask **58** is small at the light-passing portions of the light attenuation pattern **154** and increases nearer to the center of each of the lens patterns **153**, so that the amount of exposure light **44** which has passed through locations near the centers of the lens patterns **153** is larger than that of exposure light **44** which has passed through the light attenuation pattern **154**, and the exposure light **44** which has passed through locations near the centers of the lens patterns **153** reaches deep portions of the first photoreactive material **57**.

As a result, as shown in FIG. 2B, portions to which the exposure light **44** passed through the lens patterns **153** is irradiated, are cured in the form of a convex lens which is thick in the middle, and these portions form micro convex lenses **15**.

The same amount of exposure light **44** which has passed through the light attenuation pattern **154** reaches portions around the micro convex lenses **15** and the portions are cured evenly. As a result, a supporting portion **14** shaped like a board having a constant thickness which is thinner than the micro convex lenses **15** is formed, and the micro convex lenses **15** and the supporting portion **14** constitute the optical condensing portion **12**.

The supporting portion **14** is in contact and fixed with the inner peripheral surface of the hole **11**, and the micro convex lenses **15** are fixed in the hole **11** by the supporting portion **14**. In the state of FIG. 2B, the micro convex lenses **15** are also fixed on the supporting film **55**.

As for an amount of the exposure light **44** passed through the mask **58**, even exposure light passed through the centers of the lens patterns **153** is set to have the light amount less than that curing the first photoreactive material **57** totally in the depth direction, so that uncured first photoreactive material **57** is remained on the optical condensing portion **12**.

When the object **105** to be processed in this state is washed to remove the uncured first photoreactive material **57**, a substrate **106** to be processed having a cavity **61** formed on the optical condensing portion **12** in the hole **11** is obtained as shown in FIG. 2C.

Next, as shown in FIG. 3A, liquid first filling material **62** is injected into the cavity **61**.

When the hole **11** has been closed by the optical condensing portion **12**, the first filling material **62** does not leak even if the supporting film **55** has been removed. However, when the hole **11** has not been closed by the optical condensing portion **12**, the supporting film **55** is not removed to be remained and the bottom face of the hole **11** is closed by the supporting film **55**.

In either case, as shown in FIG. 3A, an object **107** to be processed having the cavity **61** filled with the first filling material **62** is formed. The first filling material **62** is disposed in the hole to the extent that it protrudes from the surface of the object **107** to be processed.

When the first filling material **62** is cured in this state, cured material **63** of the first filling material **62** is formed on the optical condensing portion **12** in the hole **11**.

The first filling material **62** may have any curability including thermosetting property and photo-curability, but the cured material **63** needs to be transparent to an optical signal.

The bottom face of the cured material **63** is in close contact with the optical condensing portion **12**, and the top of it protrudes upward from the surface of the object **108** to be processed.

Next, when the surface of the object **108** to be processed having the cured material **63** is grinded to remove the portion of the cured material **63** protruding from the surface of the object **108** to be processed, an object **109** to be processed in which a filling portion **13** having a plane surface is disposed on the optical condensing portion **12** in the hole **11** is obtained as shown in FIG. **3C**.

The filling portion **13** and the optical condensing portion **12** are in close contact with each other, and constitute a lens section **10**. Since the bottom faces of the micro convex lenses **15** and the bottom face of the supporting portion **14** are flat, an optical signal almost vertically irradiated to the lens section **10** enters the inside thereof vertically.

Furthermore, since the surface of the lens section **10** is flat, the irradiated optical signal enters the inside of the lens section **10** without being scattered and is output to the outside of the lens section **10** without being dispersed.

The refractive index of material consisting of the filling portion **13** (cured first filling material) is less than that of material consisting of the micro convex lenses **15** (cured first photoreactive material), and an optical signal passing through any one of the micro convex lenses **15** is condensed by the micro convex lens **15**, as described above.

In this embodiment and below-mentioned embodiments, it is desirable that the refractive index of the micro convex lens **15** be 1.05 or more times larger than the refractive index of the filling portion **13**. As an example, the micro convex lens **15** may be made of epoxy resin having the refractive index of 1.584, and the filling portion **13** may be made of epoxy resin having the refractive index of 1.448.

Resin consisting of the micro convex lenses **15** and resin consisting of the filling portion **13** need to be transparent to an optical signal and have refractive indexes satisfying the above relation, and may be various resin such as silicon resin and acrylic resin in addition to epoxy resin.

The supporting film **55** may be removed before or after polishing the filling material **63**. After removing the supporting film **55**, the metal films **51** and **52** are patterned to obtain an object **110** to be processed having wiring layers **36** and **37** on the insulating layers **32** and **33** as shown in FIG. **4A**.

Next, resin layers are formed on the object **110** to be processed and patterned to obtain an object **111** to be processed having protection layers (solder resist films) **45** and **46** which are the resin layers as shown in FIG. **4B**.

In the protection layer **45** or **46**, openings **38** are formed at predetermined locations, and the surface of the outermost wiring layer **36** or **37** is exposed to the bottom face of the openings **38**. The outermost wiring layer **36** or **37** is covered at portions other than the opening **38**.

Next, optical waveguides are adhered on one side of the object **111** to be processed. Here, as shown in FIG. **4C**, optical waveguides **47** in three layers are attached on a side on which the optical condensing portion **12** is located. The object **112** to be processed is cut by a dicing device or the like to form notch **50**, which have surface **54** inclined about 45 degrees to the optical waveguides **47**, in portions of the optical waveguides **47** on the extension lines of the optical axes **56** of the micro convex lenses **15**.

After the object **113** to be processed in this state is brought into a film deposition apparatus and metal layer is formed on

one side of the object **113** to be processed including the inside of the notch **50** and the surfaces of the optical waveguides **47**, and the metal layers outside the notch **50** is removed. At that time, as shown in FIG. **5B**, reflecting layer **53** which is a metal layer remained on the inclined surfaces **54** of the notch **50**, is formed, and the optical and electrical circuit board **1a** of the first embodiment of the present invention is obtained.

The reference numeral **49** in this figure denotes a reflector constituted by a notch **50**, the inclined surface **54** thereof, and a reflecting layer **53**. An optical signal input from a micro convex lens **15** to a reflector **49** or an optical signal input from an optical waveguide **47** to a reflector **49** is reflected not by the surface but by the bottom face of the reflecting layer **53**, and the traveling direction of the optical signal is changed about 90 degrees.

In the optical and electrical circuit board **1a** of the first embodiment, the micro convex lenses **15** are fixed in the hole **11** by the supporting portion **14**. However, the optical and electrical circuit board **1a** of the present invention does not necessarily need to have the supporting portion **4**.

For example, after the object **104** to be processed in which the hole **11** closed by the supporting film **55** at the bottom face is filled with the first photoreactive material **57** has been obtained, the first photoreactive material **57** is exposed to light through a mask having a pattern by which the supporting portion **14** is not formed and is different from the above-described mask **58**.

For example, the mask **59** in FIG. **12B** has the same lens patterns **153**, and a light-shielding pattern **155** constituted by light-shielding portions **151** is disposed outside the lens patterns **153**. Thus, exposure light **44** does not pass through the outside of the lens patterns **153**. When exposure light which has passed through the mask **59** is irradiated to the first photoreactive material **57** and the portions to which exposure light is irradiated are cured, isolated micro convex lenses **15** having no supporting portion are formed as shown in FIG. **6A**.

The micro convex lenses **15** are fixed on the a supporting film **46**, but the hole **11** around the micro convex lenses **15** is filled with uncured first photoreactive material **57**, so that the micro convex lenses **15** are not fixed to the inner peripheral surface of the hole **11**.

Next, when the object **125** to be processed is washed to remove the uncured first photoreactive material **57**, an object **126** to be processed having the micro convex lenses **15** fixed on the supporting film **46** in the hole **11** is obtained as shown in FIG. **6B**.

When first filling material is injected into the hole **11** of the object **126** to be processed to the extent that the surface of the first filling material protrudes and then, the first filling material is cured. An object **127** to be processed having cured first filling material **63** formed in the hole **11** is obtained as shown in FIG. **6C**.

Next, when the portion of the cured material **63** protruding from the surface of the object **127** to be processed is grinded and removed by a grinder or the like to form a filling portion **13** having a plane surface, and the support film **46** is removed as shown in FIG. **7A**, an object **128** to be processed is obtained. When the metal layers **51** and **52** of the object **128** to be processed are patterned, an object **129** to be processed having patterned wiring layers **36** and **37** as outermost layers is obtained.

After cured material **63** has been formed by curing the first filling material, the isolated micro convex lenses **15** are fixed to the inner peripheral surface of the hole **11** by the cured

## 11

material **63**, so that the micro convex lenses **15** do not drop out of the hole **11** even if the supporting film **46** has been removed.

Next, as shown in FIG. 7C, when patterned protection layers **45** and **46** which are in close contact with the outermost wiring layers **36** and **37**, are formed, and then, optical waveguides **47** are attached to the protection layer **46**, and reflector **49** is formed, an optical and electrical circuit board **1d** which is a variation of the embodiment of the present invention is obtained.

The optical and electrical circuit board **1d** of this variation can be used instead of the optical and electrical circuit board **1a** of the first embodiment (or the optical and electrical circuit board **1b** of the second embodiment or the optical and electrical circuit board **1c** of the third embodiment described later) to mount the optical-electrical signals conversion substrate **6, 7** in order to obtain an optical and electrical circuit board having the optical-electrical signals conversion substrate **6, 7**.

In the above method, the micro convex lenses **15** are formed first and the filling portion **13** is formed next. However, the method of the present invention is not limited to this.

In the case that micro convex lenses **15** are disposed in the same locations as those of the first optical and electrical circuit board **1a** of the first embodiment and the optical and electrical circuit board **1d** of the variation, an object **102** to be processed having a hole **11** penetrating it in the thickness direction as shown in FIG. 1B is formed. Then, as shown in FIG. 8A, a supporting film is attached on a side opposite to a side on which a supporting film is attached when the optical and electrical circuit board **1a** of the first embodiment or the optical and electrical circuit board **1d** of the variation is formed.

The reference numeral **133** in FIG. 8A denotes an object to be processed in this state, and one end of the hole **11** is closed by a supporting film **66**.

The object **133** to be processed is placed in such a manner that the supporting film **66** faces vertically downward and the opening end of the hole **11** faces vertically upward, and as shown in FIG. 8B, liquid second photoreactive material **67** is injected into the hole **11**. For the second photoreactive material, photo-curing material is used.

In FIG. 8B, an object **134** to be processed is illustrated as upper part of the sheet shows vertical lower side and bottom part of the sheet shows vertical upper side, as in contrast to an object to be processed in FIG. 2A or FIG. 3A. At vertical downward and near the supporting film **66** of the object **134** to be processed having the second photoreactive material **64** disposed in the hole **11**, a mask **6S** is disposed, as shown in FIG. 8C, exposure light is irradiated to the mask **68**.

The supporting film **66** is transmissive to exposure light **44**. The exposure light **44** which has passed through the mask **68** and the supporting film **66** is irradiated to the photoreactive material **67** to form a filling portion **13** cured in a form corresponding to the pattern of the mask **68**.

The mask **68** has a plurality of Concave lens patterns each having optical transmittance which is low in the middle and higher nearer to the outer periphery, arranged in a light attenuation pattern. When exposure light **44** which has passed through a lens pattern thereof is irradiated to the filling portion **13**, a concave part **65** is formed in the filling portion **13**. The filling portion has transparency to the optical signal.

The reference numeral **135** shown in FIG. 8C denotes an object to be processed in the state that the filling portion **13** having concave parts **65** is formed, and uncured second photoreactive material **67** is remained on the filling portion **13**.

## 12

Next, when the uncured second photoreactive material **67** is removed by washing, an object **136** to be processed having a cavity **69** on the filling portion **13** is obtained as shown in FIG. 9A.

The object **136** to be processed is placed in such a manner that the cavity **69** faces vertically upward and the filling portion **13** side faces vertically downward, and liquid second filling material is injected into the cavity **69** and is cured. The second filling material may have any curability including thermosetting property and photo-curability like the first filling material **62**.

When the second filling material is filled until it protrudes higher than the surface of the object **137** to be processed and the second filling material is cured, an object **137** to be processed having cured material **70** having the surface of which has protruded is obtained as shown in FIG. 9B. The cured material **70** is transparent to an optical signal.

As shown in FIG. 9C, the protruded portion of the cured material **70** is grinded to be flattened by a grinder or the like to form an optical condensing portion **12** made of the cured second filling material **70**.

Portions of the optical condensing portion **12** filled in the concave parts **65** of the filling portion **13** are each shaped like a convex lens to form micro convex lenses **15**. On the other hand, a flat plane is formed around the concave parts **65** of the filling portion **13**, and a portion of the optical condensing portion **12** located on the flat plane shapes a flat plate to form a supporting portion **14**.

The optical condensing portion **12** is in close contact with the filling portion **13**, and the micro convex lenses **15** are fixed inside the hole **11** by the filling portion **13** and the supporting portion **14**.

The refractive index of the cured material **70** of the second filling material consisting of the micro convex lenses is larger than that of the cured material of the second photoreactive material consisting of the filling portion **13**, so that light passing through the micro convex lenses **15** and the filling portion **13** is condensed at the boundaries between the micro convex lenses **15** and the filling portion **13**.

According to the above process, a convex lens section **10** having a filling portion **13** made of the second photoreactive material and an optical condensing portion **12** made of the second filling material obtained by the above process has the same structure as that of a convex lens section **10** having an optical condensing portion made of the first photoreactive material **57** and a filling portion made of the first filling material **62**, and after a convex lens section **10** has been formed, the optical and electrical circuit board **1b** (FIG. 5B) of the second embodiment of the present invention is obtained by the same processing as shown in FIG. 4A to FIG. 5A for the objects **109** to **113** to be processed of the first embodiment.

As shown in FIG. 10, an optical-electrical signals conversion substrate **6, 7** is mounted on the optical and electrical circuit board **1b** of the second embodiment as in the case of the optical and electrical circuit board **1a** of the first embodiment to obtain an optical and electrical circuit board **2b, 3b**.

In the optical and electrical circuit board **1a** of the first embodiment, the optical condensing portion **12** is made of photo-curing material. However, in the optical and electrical circuit board **1b** of the second embodiment, the optical condensing portion **12** may be made of thermosetting resin, photo-curing material, or any other curing resin.

In the optical and electrical circuit boards **1a** and **1b** described above, the optical condensing portion **12** is disposed between the filling portion **13** and the optical waveguides **47**. However, the present invention is not limited

## 13

thereto, and the filling portion 13 may be disposed between the optical condensing portion 12 and the optical waveguides 47 by disposing the supporting film 55, 66 on the other side.

The reference numeral 1c in FIGS. 11A and 11B denotes the optical and electrical circuit board of the third embodiment of the present invention having such a structure, and the reference numerals 2c, 3c denotes the optical and electrical circuit board on which the optical-electrical signals conversion substrate 6, 7 is mounted.

The optical and electrical circuit boards 1c to 3c have the same structures as those of the optical and electrical circuit boards 1a to 3a of the first embodiment or the optical and electrical circuit boards 1b to 3b of the second embodiment except that position of the optical condensing portion 12 and the filling portion 13 change in the hole 11.

In the optical and electrical circuit boards 1c to 3c of the third embodiment, an optical signal which has traveled in an optical waveguide 47 and has been reflected by a reflector 49, firstly passes through the filling portion 13 and is then condensed by a micro convex lens 15 to enter the optical-electrical signals conversion substrate 6, 7. In contrast, an optical signal output from the optical-electrical signals conversion substrate 6, 7 is condensed by a micro convex lens 15, passes through the filling portion 13, enters a reflector 49, and is guided inside the optical waveguide 47.

Also with respect to the optical condensing portion 12 of the second or the third embodiment of the optical and electrical circuit boards 1b to 3b or 1c to 3c, the micro convex lenses 15 may be fixed in the hole 11 by the filling portion 13 without providing a supporting portion 14 as in the case of the optical and electrical circuit board 1d of the variation.

Furthermore, electronic components such as, semiconductor elements is mounted also on the optical and electrical circuit boards 1c to 3c of the third embodiment as in the case of the optical and electrical circuit boards 1a to 3a of the first embodiment of the present invention or the optical and electrical circuit boards 1b to 3b of the second embodiment of the present invention.

In the above-described optical and electrical circuit boards 1a to 1c, 1b to 3b, and 1c to 3c, the portion of the holes 11 other than the optical condensing portion 12 can be filled with air without providing the filling portion 13 as long as the micro convex lenses 15 are fixed to the inner peripheral side surface of the hole 11 by the supporting portion 14.

The thickness of the supporting portion 14 and the thicknesses of the micro convex lenses 15 can be changed by changing the amount of exposure light 44 and/or the ratio between the light-shielding portions 151 and the light-passing portions 152 of the mask 58 and 59.

Furthermore, when the thickness of the supporting portion 14 and/or the thicknesses of the micro convex lenses 15 are changed, the distances between the micro convex lenses 15 and the light-emitting/receiving elements 82, 92 can be also changed.

Furthermore, the distances between the micro convex lenses 15 and the light-emitting/receiving elements 82, 92 can also be changed by changing the thickness of the multi-layer substrate section 30.

Although the first and second photoreactive material and the first and second filling material are liquid, they are not necessarily limited to liquid, and may be paste material or powder material as long as they can be disposed at a predetermined location in the hole 11.

In the above embodiments, the optical condensing portion 12 is made of first photoreactive material in one exposure step, but may be formed in two or more steps. For example, first photoreactive material is exposed to light through a mask

## 14

having no lens section to form a supporting portion 14 having no micro convex lens as shown in FIG. 13A, and the soluble portion thereof is then removed. After that, first photoreactive material is filled again and exposed to light to form micro convex lenses 15 on the supporting portion 14 as shown in FIG. 13B.

In the above description, the first or second photoreactive material is photo-curing material. However, the optical condensing portion 12 may be formed by using photodissolution material. When photodissolution material is used, portions to which exposure light is irradiated become soluble portion and portions to which exposure light is not irradiated become cured portion, so that when forming a component having the same shape as that in the case that photo-curing material is used, the pattern of a mask is reversed from that in the case that photo-curing material is used. In short, when the light-shielding portions in the case of photo-curing material are changed to light-passing portions and the light-passing portions in the case of photo-curing material are changed to light-shielding portions, an optical condensing portion and a filling portion can be formed in the same process as that in the case of photo-curing material. However, photo-curing material has more handling and cost advantages than photodissolution material.

The embodiments of the present invention is configured as described above, and when the photoreactive material is photo-curing material, a portion where exposure light has been irradiated is cured to become a cured portion, and a portion to which exposure light is not irradiated becomes a soluble portion. When the photoreactive material is photodissolution material, it is temporarily cured and then exposed using a mask. The portion to which exposure light has been irradiated becomes a soluble portion and a portion to which exposure light is not irradiated becomes a cured portion.

In the embodiments of the present invention, exposure light which has passed through a mask is irradiated to photoreactive material disposed in a hole of an object to be processed to form a cured portion and a soluble portion, and a micro convex lens is made of the photoreactive material, or, a filling portion having a depression part is made of photoreactive resin by exposure light which has passed through the mask and liquid filling material such as thermosetting resin is disposed in the depression part and is cured to form a micro lens.

It is easy to align an object to be processed with a mask, so that a micro convex lens can be disposed in an accurate position as compared with the case that a micro convex lens formed separately from the object to be processed is mounted.

Furthermore, a micro convex lens can be formed by an exposing and developing process similar to that of patterning a wiring layer, a protection layer, and the like in an object to be processed, so that the workability is high.

Furthermore, a micro convex lens is incorporated in an optical and electrical circuit board, so that the optical and electrical circuit board can be handled easily.

As mentioned above, preferred embodiments of the present invention have been described. However, the present invention is not limited to these embodiments, and variations and modifications may be made in accordance with the spirit and scope of the present invention.

Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.

What is claimed is:

1. A method of manufacturing an optical and electrical circuit board; the method comprising:
  - providing a lens hole penetrating an object to be processed of which a first electrical wiring layer is arranged on both faces of a base layer, an insulating layer is formed on each of the first electrical wiring layers, and a second electrical wiring layer is formed on each of surfaces of the insulating layers, in a thickness direction thereof;
  - providing a transparent supporting film on one face of the object to be processed so as to close one end of the lens hole;
  - injecting a first photoreactive material into the lens hole from an opening at the other end of the lens hole;
  - exposing exposure light to the first photoreactive material from the supporting film side;
  - forming a cured portion and a soluble portion of the first photoreactive material by partially exposing the first photoreactive material to the exposure light passed through the supporting film; and then
  - dissolving and removing the soluble portion of the first photoreactive material for development so as to form a micro convex lens in the lens hole.
2. The method of manufacturing an optical and electrical circuit board according to claim 1, further comprising:
  - forming a cured portion in a region between a portion in which the micro convex lens is formed and an inner peripheral side surface of the lens hole, the cured portion constituting a connecting portion which connects the micro convex lens to the inner peripheral side surface of the lens hole.
3. The method of manufacturing an optical and electrical circuit board according to claim 1, further comprising:
  - filling first filling material having optical transparency and a refractive index smaller than a refractive index of the micro convex lens into the lens hole in which the micro convex lens has been formed; and
  - curing the first filling material to form a filling portion.
4. The method of manufacturing an optical and electrical circuit board according to claim 1,
  - wherein the first photoreactive material is exposed using a mask including a plurality of lens patterns in which circular light-shielding portions having circle shape and circular light-passing portions having circle shape are arranged alternately and concentrically and a light attenuation pattern which is located around each of the lens patterns and has linear light-shielding portions having line shape and linear light-passing portions having line shape arranged alternately.
5. The method of manufacturing an optical and electrical circuit board according to claim 4,
  - wherein the mask is configured such that an area ratio of an area of the linear light-passing portions to an area of the

- linear light-shielding portions in the light attenuation pattern is set to be less than an area ratio of an area of the circular light-passing portions to an area of the circular light-shielding portions in the lens patterns.
6. The method of manufacturing an optical and electrical circuit board according to claim 4,
  - wherein the mask is configured such that, in the lens pattern, widths of the circular light-passing portions are set to be larger nearer to a center of concentric circle, and widths of the circular light-shielding portions are set to be larger nearer to an outermost periphery of the concentric circles.
7. A method of manufacturing an optical and electrical circuit board, comprising:
  - providing a lens hole penetrating an object to be processed of which a first electrical wiring layer is arranged on both faces of a base layer, an insulating layer is formed on each of the first electrical wiring layers, and a second electrical wiring layer is formed on each of surfaces of the insulating layers, in a thickness direction thereof;
  - providing a transparent supporting film on one face of the object to be processed so as to close one end of the lens hole;
  - injecting a photoreactive material into the lens hole from an opening at the other end of the lens hole;
  - exposing exposure light to the photoreactive material from the supporting film side;
  - forming a cured portion and a soluble portion of the photoreactive material by partially exposing the photoreactive material to the exposure light passed through the supporting film; then
  - dissolving and removing the soluble portion of the photoreactive material for development to form a filling portion having a concave part in the lens hole;
  - filling a filling material having optical transparency and a refractive index higher than a refractive index of the filling portion in the concave part; and then
  - curing the filling material to form a micro convex lens.
8. The method of manufacturing an optical and electrical circuit board according to claim 7, further comprising:
  - exposing a portion in a region between a portion in which the micro convex lens is formed and an inner peripheral side surface of the hole in order to form a connecting portion which connects the micro convex lens to the inner peripheral side surface of the lens hole.
9. The method of manufacturing an optical and electrical circuit board according to claim 7, wherein the photoreactive material is exposed using a mask including a plurality of lens patterns being arranged in an light attenuation pattern, the plurality of lens pattern being shaped as concave lens having optical transmittance at a middle part being lower than optical transmittance of portions nearer to an outer periphery.

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